Technical Summary Memorandum
Dam Feasibility and Impact Analysis

Macallen Dam, Newmarket, NH

Prepared for:

Town of Newmarket, New Hampshire

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January 2014

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Acronyms

EAP	Emergency Action Plan
FERC	Federal Energy Regulatory Commission
GSE	Gomez and Sullivan Engineers, P.C.
IDF	Inflow Design Flood
LOD	Letter of Deficiency
NHDES	New Hampshire Department of Environmental Services
NHDOT	New Hampshire Department of Transportation
NHFGD	New Hampshire Fish and Game Department
OMR	Operation, Maintenance and Response Form
PAD	Pre-Application Document
PAH	Polyaromatic Hydrocarbon
Town	Town of Newmarket
USGS	United States Geological Survey

Introduction

The Town of Newmarket (Town) contracted with Gomez and Sullivan Engineers, P.C. (GSE) to evaluate the feasibility of potentially removing Macallen Dam. A deliverable from this contract is the enclosed Technical Summary Memorandum. The purpose of the Technical Summary Memorandum is to summarize GSE's major findings from our review of the existing data, literature, past studies, and input received at the first public meeting on September 16, 2013. This document includes the following:

1) Photographic documentation of the dam and impoundment under full and partial drawdown conditions;
2) Findings from due diligence research relative to the potential for contaminated sediments in the river reach (impoundment) impounded by the Macallen Dam;
3) Summary of available New Hampshire Fish and Game Department's (NHFGD) migratory fish passage estimates for the past decade at the Macallen Dam fish ladder;
4) Summary of available water quality data in the project area;
5) Summary of available New Hampshire Department of Transportation (NHDOT) information on the Route 108 Bridge (Veterans Bridge) just upstream of Macallen Dam;
6) Summary of available dam inspection reports and findings;
7) Summary of any cultural resource work that is complete when this memo is produced.

Based on our review of past dam engineering reports and input received at the first public meeting, several other important topics have been noted. We have added sections to this memo to address these topics, including:

1) Review of past hydraulics and hydrology studies of the Macallen Dam; and
2) Potential hydroelectric generation at Macallen Dam

Setting

The Macallen Dam is located on the Lamprey River in downtown Newmarket. Figure 1 is an aerial map of the impoundment. Figure 2 is a close up aerial view of the dam. Based on existing mapping and survey conducted under this contract, an existing conditions plan in the dam area was developed as shown in Figure 3. The dam is readily visible from Veteran's Bridge located immediately upstream of the dam, from the footbridge spanning the Lamprey River below the dam, and from various locations on each side of the river. There is considerable infrastructure development around the dam including buildings and parking lots as shown in Figure 2 and Figure 3. The dam creates an impoundment extending upstream approximately 2.5 miles up the Lamprey River and approximately 0.75 miles up the Piscassic River – a major tributary to the Lamprey River. The impoundment extends into Durham, NH and creates several backwater/bay areas, including an impounded area nearly circling what is referred to as Moat Island. The dam's presence has considerably backed up the flow of water in the Piscassic River from its confluence with the Lamprey River to the bedrock falls that mark the upstream extent of the Macallen Dam impoundment.

There are several condominium or apartment complexes and residential houses (homes) flanking the impoundment in the lower portion of the Macallen Dam's impoundment. The river supports recreational activity as evidenced by docks located around the residences and a boat ramp at the end of Piscassic Street. In our three on-the-water site visits to the impoundment (summer weekend, summer weekday and fall weekday) there were several kayakers, canoeists and small motorized boats observed on the impoundment. Recreational boating appeared to be heavier on the weekends during the summer than during the summer or fall weekdays.

Dam Geometry and Description

The Macallen Dam is an approximate 27-foot high stone-block dam located in downtown Newmarket, NH. The current dam was constructed in 1887, as indicated by the engraved stone on the front of the dam[1]. The dam was constructed on or near what some history books have referred to as "the First Falls." Based on cursory research in preparing our proposal, historic documents suggest there have been dams located at or near this location perhaps as far back as the late 1600's.

The dam consists of three main sections (Figure 4, Figure 5, and Figure 6): the right[2] abutment, the spillway section, and the left abutment/gate section. The right abutment is a stone-block and concrete wall, which is structurally attached to the fish ladder. The right abutment has a crest elevation of 28.47 feet[3]. Immediately below the right abutment is a brick building currently housing a commercial business. The building appears to be structurally tied to the fish ladder. The spillway is constructed of stone-block, with a crest elevation of 22.35 feet[4]. There is a small metal lip along the center of the spillway (crest elevation 22.42 feet) that further controls water levels. The lip appears to be a relic from when the dam had flashboards[5] installed. The left abutment/gate section is a stone-block and concrete section with three 7 foot by 7 foot manually-operated crest gates. The gates have a crest elevation of 16.15 feet and a

[1] GSE received information during the October 2013 drawdown that there is at least one other date-engraved stone located under the normal water line on the right abutment with a slightly different year.
[2] When referring to the left or right side of the river, it assumes one is looking in a downstream direction.
[3] All elevations in this document refer to the North American Vertical Datum of 88 (NAVD88). The GSE survey used the Geoid12a geoid.
[4] A previous survey by Wright-Pierce indicated that the dam's crest elevation was approximately 22.18 feet, a difference of 0.17 feet. This difference may be explained by a combination of both surveys' measurement accuracy.
[5] Flashboards are commonly constructed of wood and are affixed to the spillway crest to raise the water level behind the dam typically to increase hydroelectric generation.

top elevation of 23.15 feet. While the gates are 7 feet tall, the NHDES September 17, 2010 inspection report states that the gates cannot fully open and listed 5.5 feet above the crest as the maximum opening height (elevation 21.65 feet). With a gate crest elevation of 16.15 feet and a spillway crest elevation of 22.42 feet (at the metal lip), the water level behind the dam can be lowered up to 6.3 feet. The left abutment, located above the gates, has a crest elevation of 30.20 feet.

The Macallen Dam is operated as a run-of-river facility, where inflow equals outflow on a near continuous basis. This means that water levels behind the dam are typically maintained at the spillway crest elevation or higher as inflow increases. If, for example, inflow to the dam was 30 cubic feet per second (cfs), then the discharge over the spillway would be approximately 30 cfs; no water is "stored" behind the dam. During floods, inflow exceeds the discharge capacity of the spillway and gates, and water backs up behind the dam—as experienced in the May 2006, April 2007, and March 2010 floods, among others.

Dam Hydraulics

The Macallen Dam has two means of passing water: the overflow spillway and the crest gates. During normal hydrologic conditions, flow passes exclusively over the spillway (or a small amount through the fish ladder during certain times of the year). During high flow or flood events, the crest gates are typically opened to allow more flow to pass without overtopping the dam abutments. During some recent extreme flood events (May 2006, April 2007, March 2010), the dam abutments were overtopped even with the gates open (Figure 7). The hydraulic modeling conducted as part of this study will be used to estimate the flow through the dam spillway and crest gates. The purpose of this section is to briefly describe the equations, assumptions and calculations that will be conducted as part of the hydraulic modeling at the dam.

Dam spillways are typically modeled as broad-crested weirs. The amount of water passing over a weir (note weir and spillway are used interchangeably) is calculated using the following equation:

$Q = CLH^{1.5}$, where

Q = is quantity of flow passing over the weir (cfs),
C= is the weir coefficient (feet$^{0.5}$),
L= is the length of the weir (feet), in this case the length of the spillway is 70 ft, and
H= is the depth of water above the weir crest (feet).

Figure 8 shows the dimensions on an example broad-crested weir.

The weir coefficient typically varies based on the depth of water above the spillway crest and the spillway geometry. While the dam's geometry is different than a typical broad-crested weir, we believe it is prudent (and slightly conservative) to model the dam spillway as a broad-crested weir. A typical weir coefficient for a broad-crested weir with minimal depth of water (H) over the spillway is approximately 2.63. In general, however, weirs become more efficient (higher C values) as the depth of water above the spillway crest increases. For depths of water (H) less than 4.0 feet, the dam will be hydraulically modeled with a weir coefficient between 2.48 and 3.32. For water depths (H) greater than 4.0 feet, the dam will be hydraulically modeled with a weir coefficient of 3.32. The resulting stage[6] versus discharge curve for the Macallen Dam spillway is shown in Figure 9. A detailed description on the weir coefficient used for the Macallen Dam is included in Appendix A.

The dam's crest gates are typically only opened during high flow or flood events, during which they are fully submerged (meaning the water moving through the gate openings are under pressure). Thus, they will be modeled as an orifice. Flow through an orifice is calculated using the equation:

$Q = CA\sqrt{2gh}$, where

- C= is an orifice coefficient (unitless),
- A= is the orifice area (feet^2), in this case, each gate has a usable orifice opening of 5.5 ft by 7 ft or 38.5 feet^2,
- G= is gravitational acceleration (32.2 feet/sec^2) and
- h= is the net head through the orifice (feet).

The orifice coefficient, C, will be approximated as 0.6, which is a typical value. The orifice area, A, is 38.5 feet^2 (7-ft wide x 5.5-ft high) per gate. The net head, h, was calculated as if the orifice was submerged. A photograph from the March 2010 flood shows that flow through the gates is partially impeded (backwatered) by an angled wall on river left (Figure 10). The left and center gates are clearly impacted by the backwater, while it is unclear if the right gate is impacted by the backwater. We conservatively assumed that the downstream tailwater elevation is equal to the elevation of the open crest gate (21.65 feet) for all three gates. This means we are estimating less gate hydraulic capacity than if the angled wall was not present causing a backwater. The resulting stage versus discharge curve for the Macallen Dam gates is shown in Figure 11.

[6] Stage refers to the water surface elevation above the spillway crest.

Figure 12 shows a combined gate and spillway stage versus discharge rating curve for the Macallen Dam. The graph shows that at approximately one foot below the right abutment (28.47 feet), the dam can pass approximately 3,458 cfs over the spillway and 1,452 cfs through the gates, for a total of 4,910 cfs. The figure also shows that as the water surface increases, the gates pass an increasingly small proportion of the flow passing over the dam. At an impoundment elevation of 28.4 feet, the gates can pass a maximum of approximately 30% (1,447 cfs) of the total flow passing the dam (4,863 cfs).

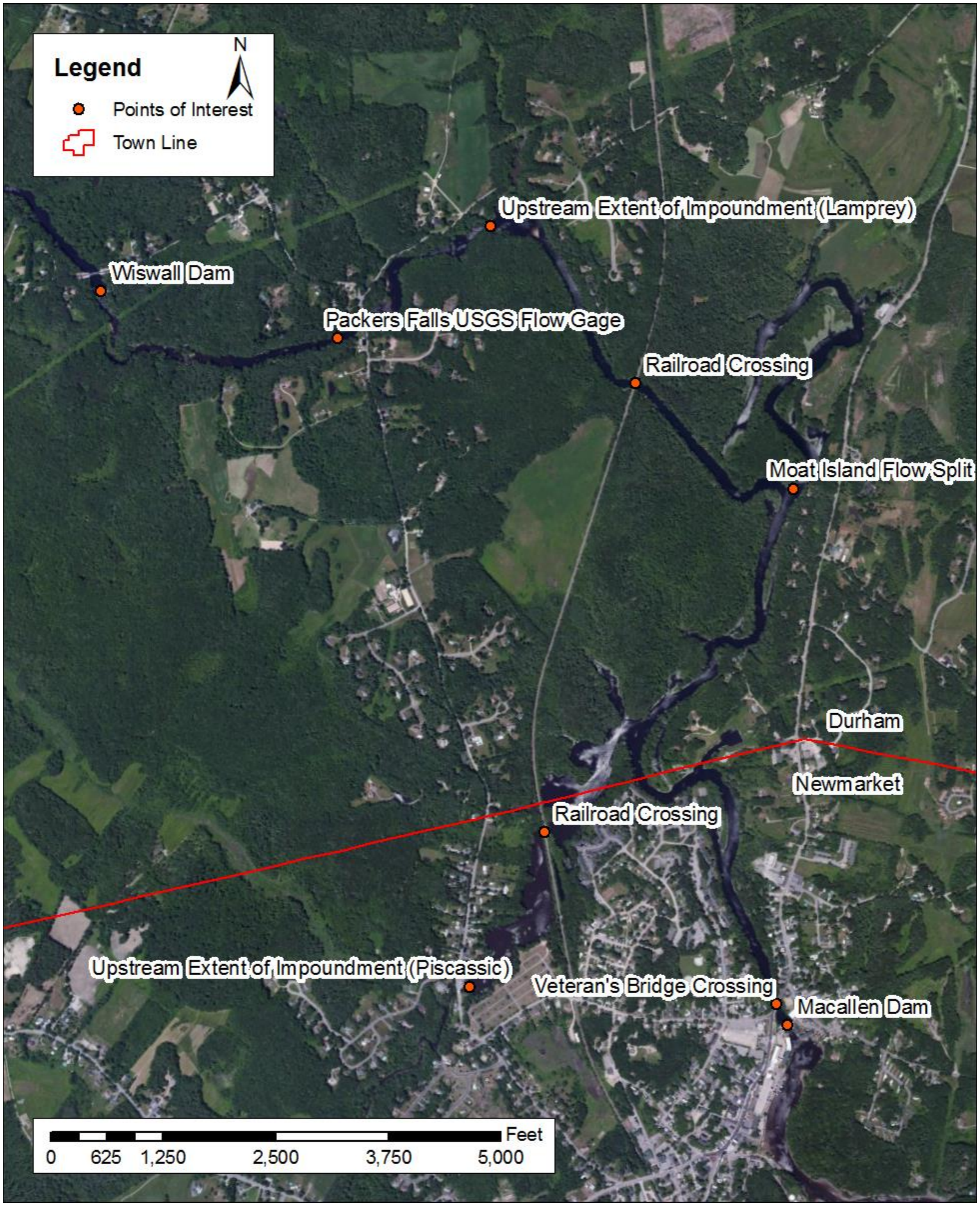

Figure 1: Dam and impoundment overview.

Figure 2: Aerial close-up of Macallen Dam.

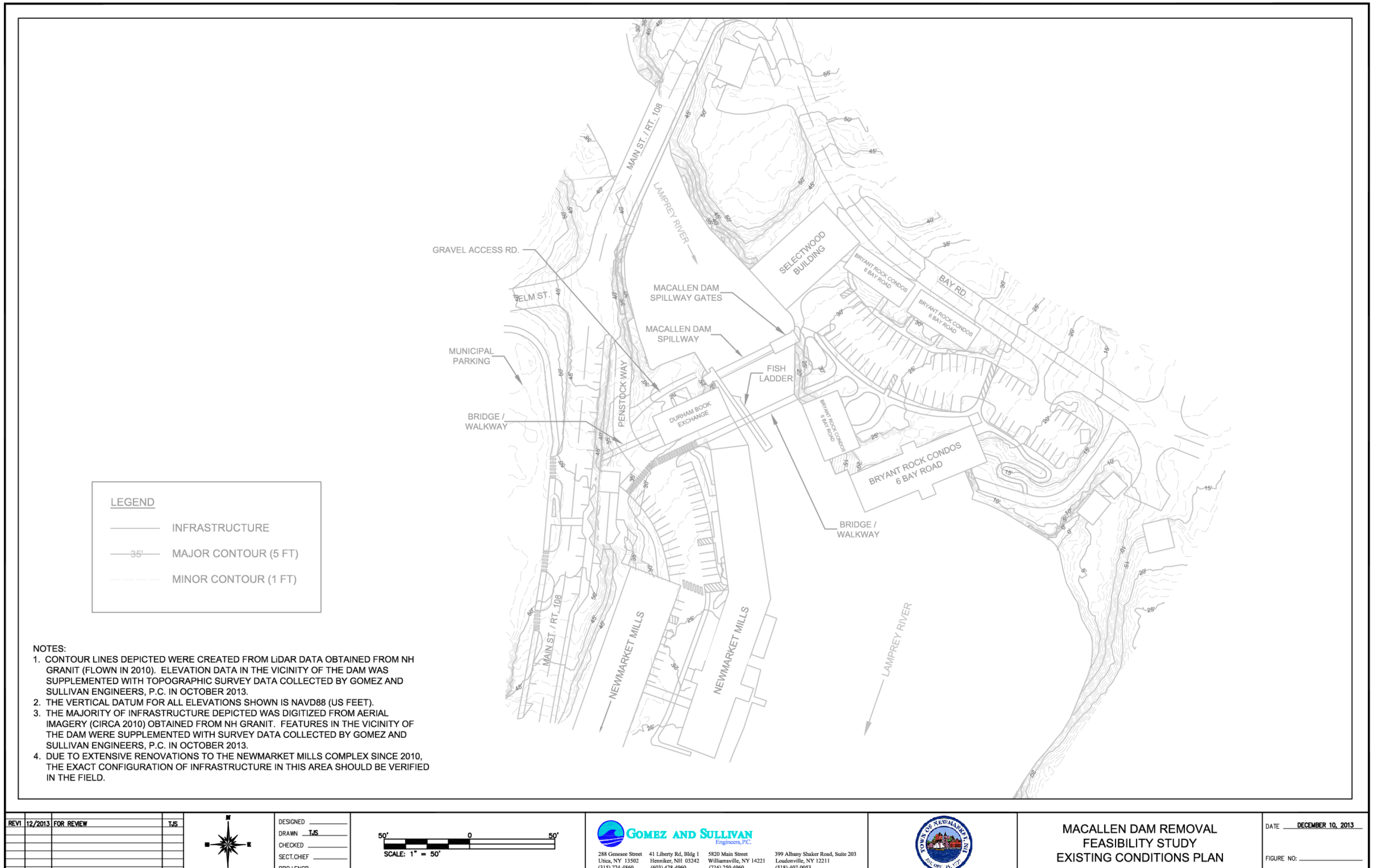

Figure 3: Existing conditions base map of Macallen Dam.

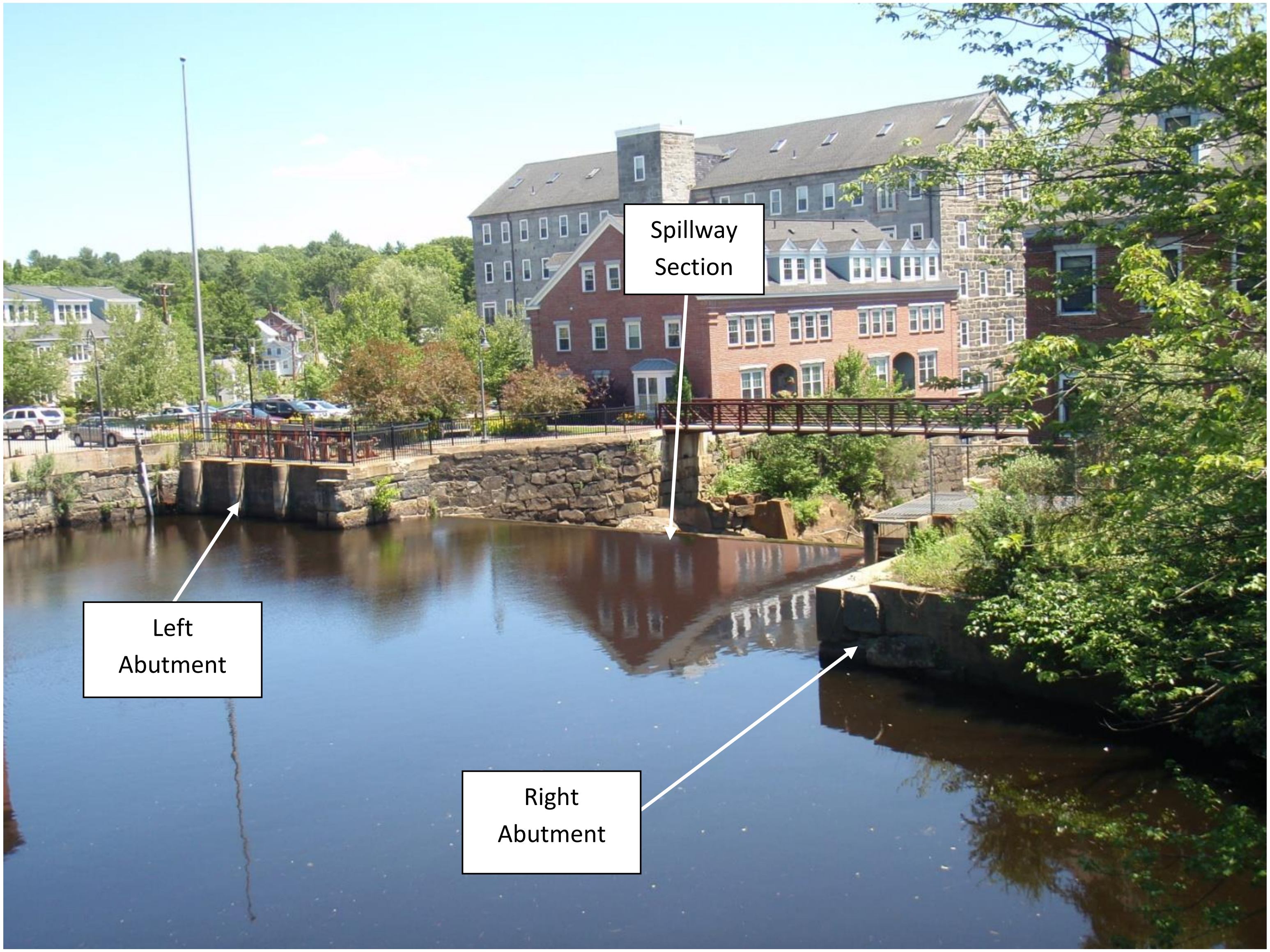

Figure 4: Looking downstream toward Macallen Dam's left abutment, right abutment and spillway sections. Photo taken July 2012.

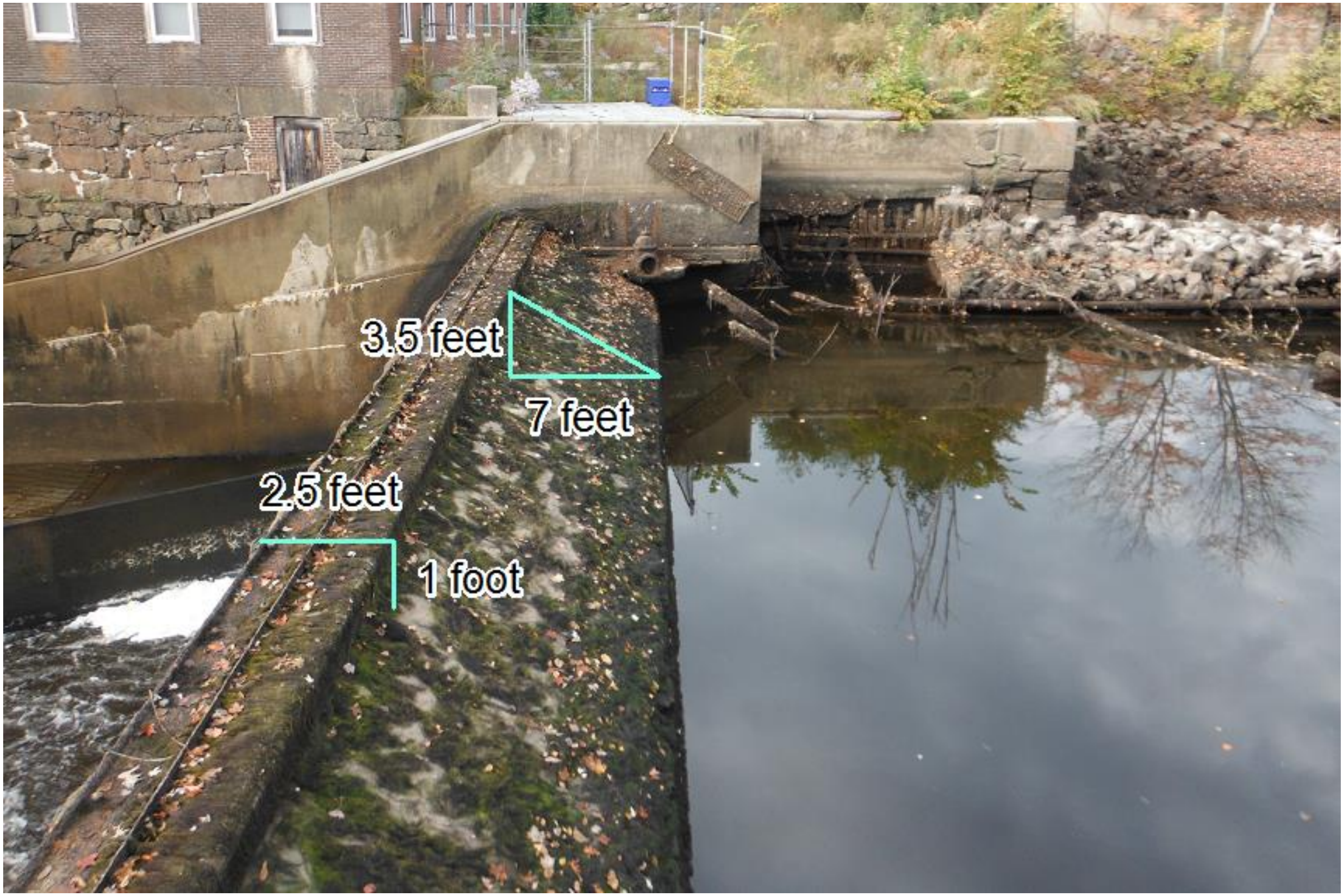

Figure 5: Photo of the dam's right abutment and spillway sections, including geometry of the sloped upstream face of the dam. Photo taken during the October 2013 drawdown. Note the metal lip running along the center of the spillway crest.

Figure 6:Left abutment and crest gates. Photo taken during the October 2013 drawdown.

Figure 7: Macallen Dam during the March 16, 2010 flood event. Flow is approximately 6,710 cfs. Photo is taken from the right abutment, looking toward the spillway and left abutment. Photo source: NHDES Dam Bureau.

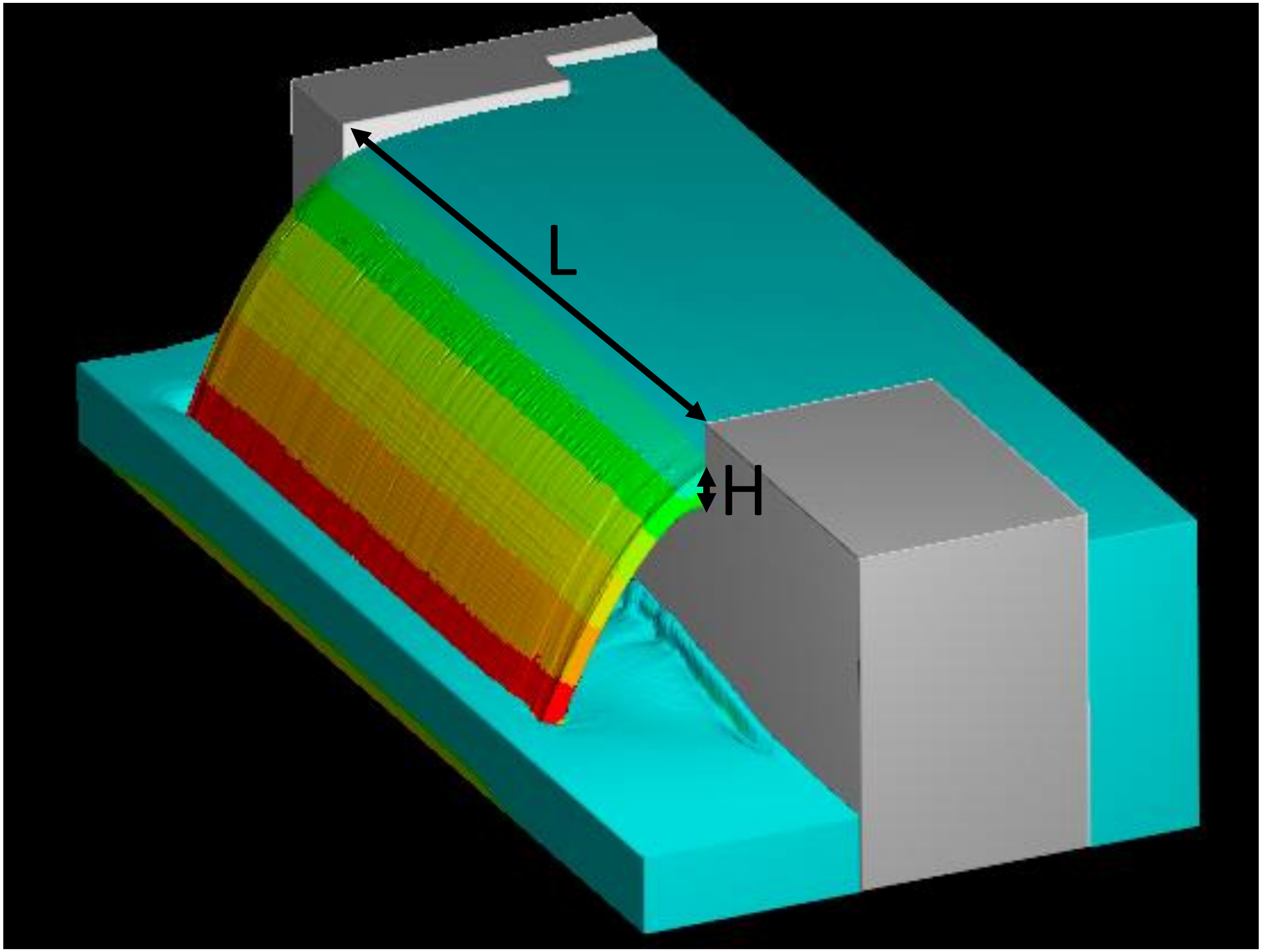

Figure 8: Three-dimensional representation of a broad-crested weir.

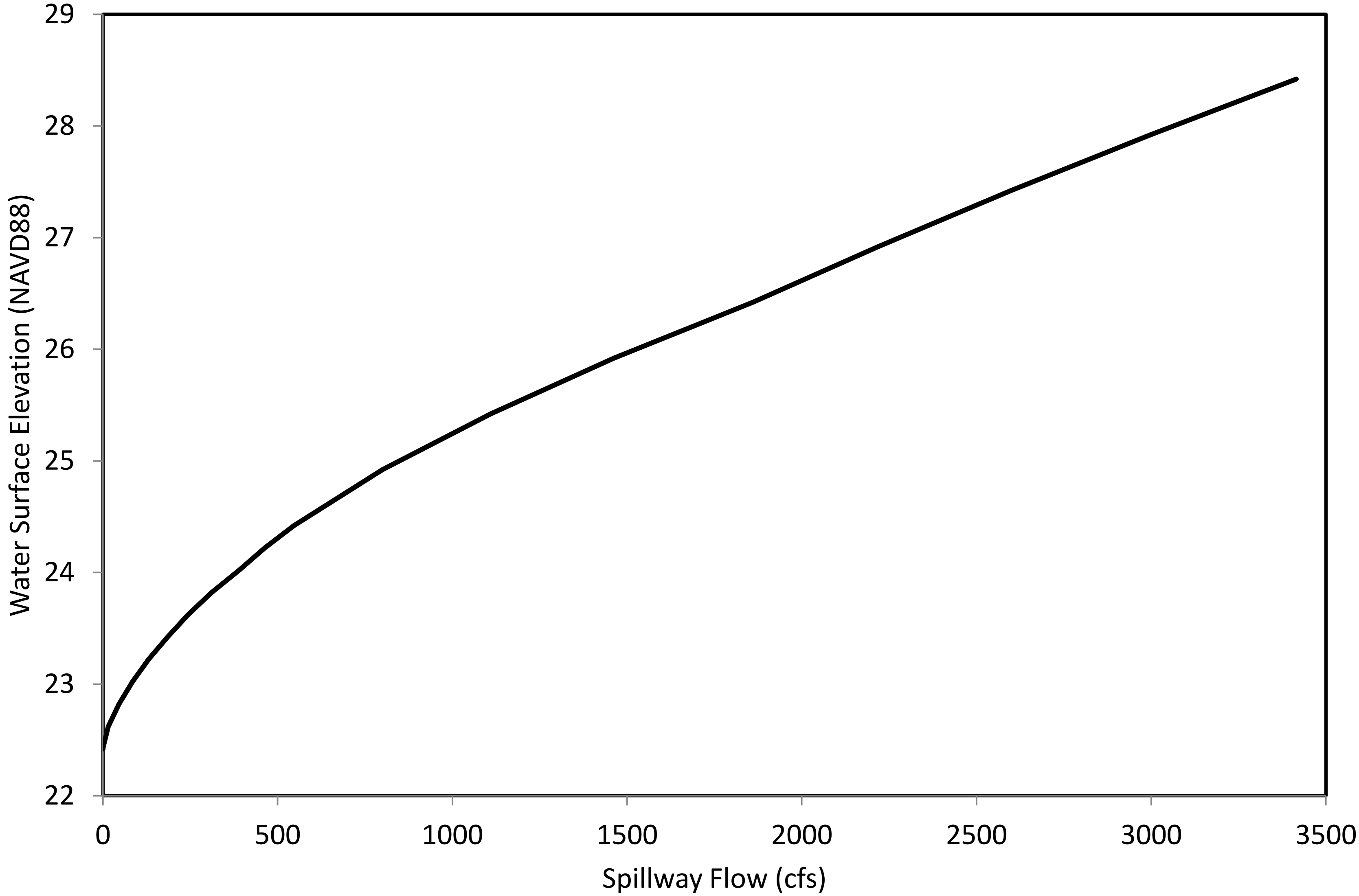

Figure 9: Macallen Dam spillway elevation versus flow rating curve. The spillway crest is at elevation 22.42 feet.

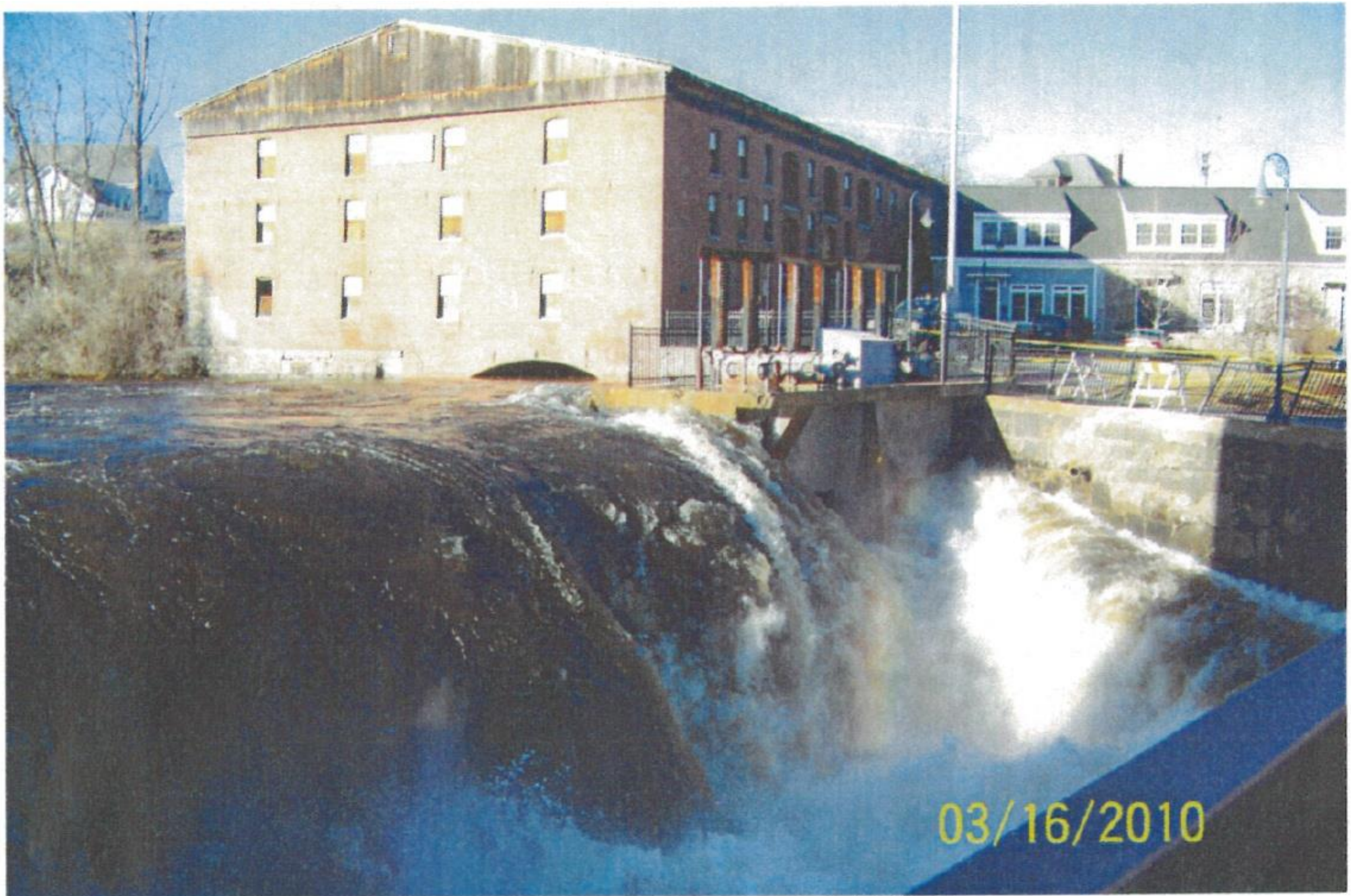

Figure 10: Looking upstream at the Macallen Dam spillway and left abutment during the March 2010 flood. Flow is approximately 6,710 cfs. Note backwater downstream of the gate structure due to the angled wall on river left. Photo source: NHDES Dam Bureau.

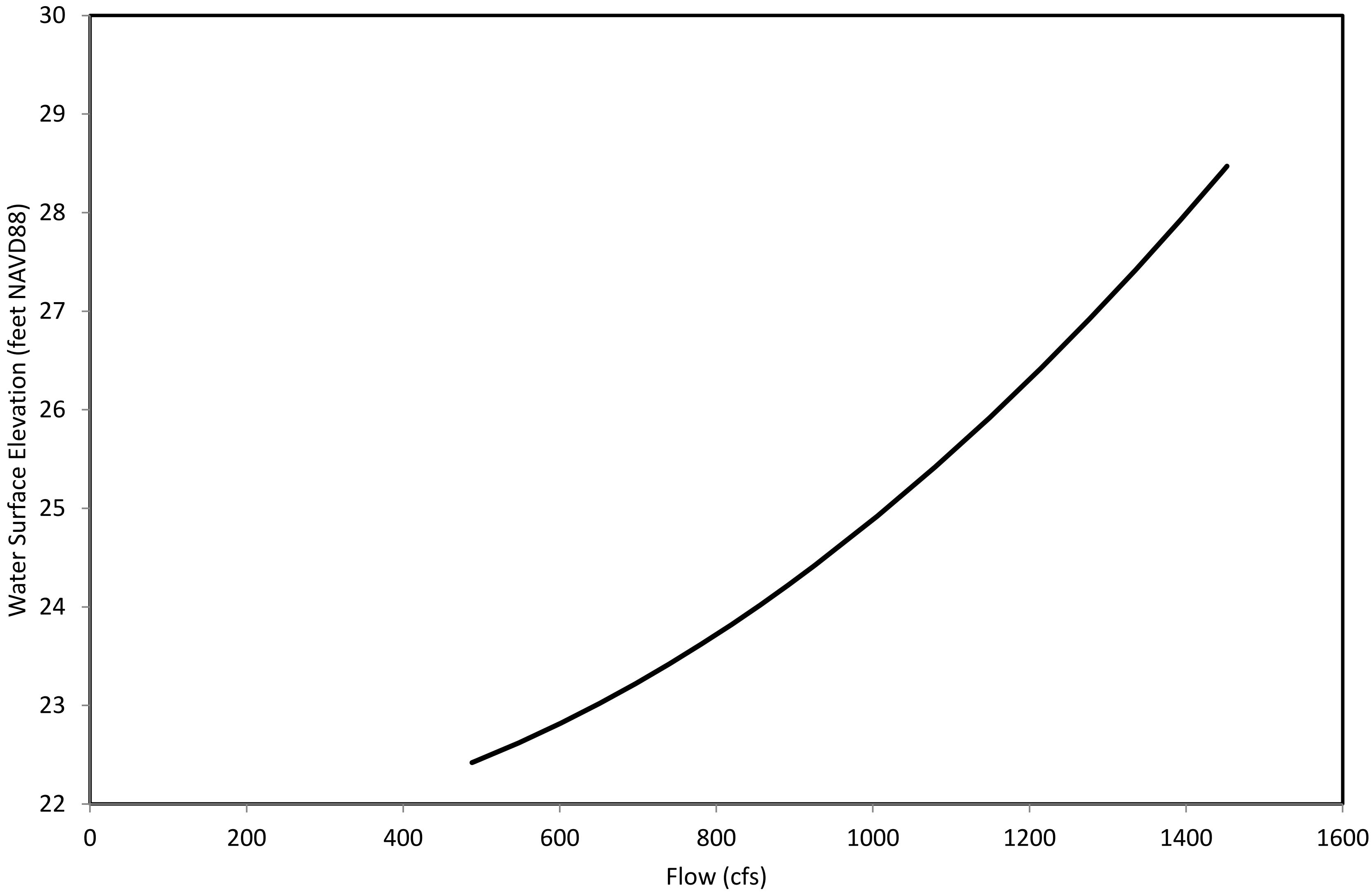

Figure 11: Macallen Dam crest gates elevation versus flow rating curve. Flows below the spillway crest elevation were not calculated. Calculations assume all three gates are fully open.

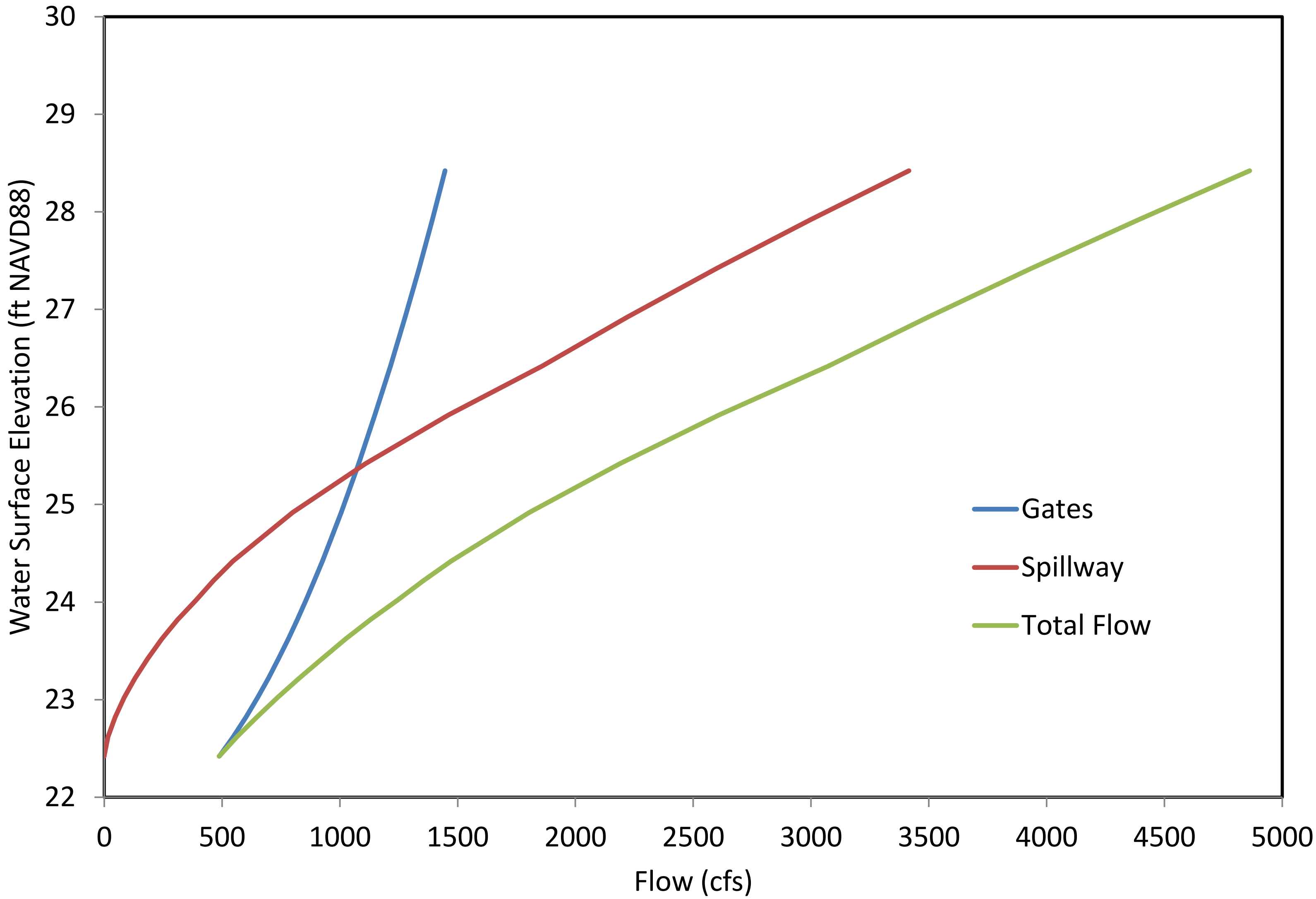

Figure 12: Macallen Dam water surface elevation versus flow for the gate, spillway and total dam flow.

Regulatory Oversight and Letter of Deficiency

The New Hampshire Department of Environmental Services (NHDES) Dam Bureau is responsible for dam oversight in New Hampshire. NHDES classifies dams as Class AA, Class A, Class B, or Class C. The hazard classification is based on a dam's size (height), volume of impounded water and the potential loss of life, structures, and property if dam failure were to occur. The Macallen Dam is classified as a Class C structure (i.e., high hazard dam). A high hazard classification means that loss of life is likely to occur if the dam were to fail. NHDES regulations (Env-Wr 101.09) state that

"Class C Structure means a dam that has a high hazard potential because it is in a location and of a size that failure or misoperation of the dam would result in probable loss of human life as a result of:

- *(a) Water levels and velocities causing the structural failure of a foundation of a habitable residential structure or a commercial or industrial structure which is occupied under normal conditions;*
- *(b) Water levels rising above the first floor elevation of a habitable residential structure or a commercial or industrial structure which is occupied under normal conditions when the rise due to dam failure is greater than one foot;*
- *(c) Structural damage to an interstate highway which could render the roadway impassable or otherwise interrupt public safety services;*
- *(d) The release of a quantity and concentration of materials which qualify as "hazardous waste" as defined by RSA 471-A:2 VI; or*
- *(e) Any other circumstance which would more likely than not cause one or more deaths."*

As stated in the 2010 Letter of Deficiency (LOD) issued by the NHDES to the Town, the Macallen Dam is classified as a high hazard dam because the dam's right abutment is integral to the foundation of the historic brick mill building (current proprietor, Durham Book Exchange) on river right. The state's concern is that if the dam were to breach or overtop, its failure could impact the foundation of the historic brick mill building. This building is a commercial structure that is occupied under normal conditions[7], as described in term (a) above.

NHDES requires that each dam classification must pass a specific discharge capacity, which means "*the amount of water which can safely pass the structure through its normal discharge channels*" (Env-Wr 101.16).

NHDES regulations (Env-Wr 303.11) state the following relative to discharge capacity:

[7] Past inspections (prior to 2010) did not take this building into account because it was previously uninhabited.

(a) *All Class A, Class B, or Class C dams constructed prior to February 19, 1981 shall pass the flows indicated below* *<u>with one foot of freeboard and without manual operations</u>:*
   (1) *Class A dams shall pass a 50-year flood, or at the owner's option, the site specific inflow design flood;*
   (2) *Class B dams shall pass the 100-year flood, or at the owner's option, the site specific inflow design flood; and*
   (3) *Class C dams shall pass 250% of the 100-year flood, or at the owner's option, the site specific inflow design flood.*

As a Class C dam, the Macallen Dam must pass 250% of the 100-year flood, or at the owner's option, the site specific inflow design flood (IDF)[8]. Wright-Pierce conducted a detailed study and concluded that the IDF is equivalent to the 100-year flood at the Macallen Dam. This effectively means that for flows above the 100-year flood, failure of the dam is not anticipated to cause any additional loss of life or property beyond what would already have occurred from a flood of that size. The Macallen Dam's 100-year flood flow is 10,259 cfs after taking the Lamprey-Oyster "flow split" into account[9]. It is also worth noting that the dam's previous classification as a Class B dam (i.e., significant hazard dam) prior to 2008 would still require passage of the 100-year flood or the IDF. Since the IDF is being used as the design flood, and it is the same as the 100-year flood, the dam's discharge capacity requirement would not change even if the dam was considered a significant hazard dam rather than a high hazard dam.

The "one foot of freeboard" requirement means that the water depth over the dam spillway under the 100-year flood must be at least one foot below the lowest abutment. For the Macallen Dam, the right abutment (elevation 28.47 feet) is the lower abutment. This means that the 100-year flood flow must pass with a water surface elevation of 27.47 feet or less at the dam.

The term "without manual operations" is not explicitly defined in the dam safety regulations. Based on our experience with NHDES Dam Safety, this means that any structure requiring human intervention is considered manual operations. For example, the three gates at the dam's left abutment require a human to either physically or electrically open the gates. Thus, these gates are not counted toward the dam's discharge capacity even though the town would normally open them during a flood event.

[8] The IDF is the flow at which dam failure is not anticipated to cause any additional impacts to life or property.
[9] Under extreme floods, the Lamprey River water surface elevations rise high enough to flow over the typical watershed boundary. When this happens some of the Lamprey River's flow diverts into the Oyster River watershed, rather than passing downstream to the Macallen Dam. This phenomena is explained in detail later in this document.

Letter of Deficiency and Study Timeline

NHDES initially sent the Town a LOD for Macallen Dam in May 2008. Since then, there has been a series of follow-up studies, a new LOD in September 2010, and other correspondence between NHDES and the Town. The purpose of this section is to summarize the actions and correspondences that have occurred since the 2008 LOD was issued up through the issuance of the most recent Wright-Pierce letter report dated February 6, 2013.

2008 Hazard Reclassification (April 7, 2008): Based on NHDES's April 7, 2008 Macallen Dam inspection report, the Macallen Dam's hazard classification was changed from a Significant Hazard (Class B) dam to a High Hazard (Class C) dam. The classification change at the time was based on anticipated flooding in downstream apartments in the event of a dam breach. The hazard reclassification increased the dam's required design flow from the 100-year flood or the IDF to 2.5 times the 100-year flood or the IDF. The inspection did not note any signs of habitation in the historic mill building (current proprietor, Durham Book Exchange) that is structurally tied to the right abutment, and that building was thus not considered in the hazard classification as part the 2008 reclassification and LOD.

NHDES 2008 Letter of Deficiency (May 5, 2008): The NHDES sent the Town a LOD on May 5, 2008. This LOD superseded a previously issued LOD from 2004. The 2008 LOD noted that some items from the 2004 LOD were not addressed. The LOD included a timeline for addressing the deficiencies, which included submitting an Operations, Maintenance and Response (OMR) form to NHDES, developing an Emergency Action Plan (EAP) and inundation maps, and various other structural and maintenance-related items. The LOD also indicated that the Town must submit a permit application with plans and specifications to increase the dam's discharge capacity so that it can "safely pass the design flow (2.5 Q100 or IDF) with one foot of freeboard and no operations."

Wright-Pierce Dam Assessment (began in 2009): In 2009, the Town hired Wright-Pierce to conduct an overall assessment of Macallen Dam, including a structural inspection and analysis of the dam, drafting an EAP, dam breach modeling and inundation mapping.

Wright-Pierce Structural Analysis and Recommendations (March 8, 2010): Wright-Pierce's letter report summarized the results of their November 7, 2009 inspection. Several repairs and rehabilitation measures were suggested to be undertaken within two years. The report indicated that Wright-Pierce did not perform a structural or stability analysis of the dam.

Wright-Pierce Structural Repair Cost Estimate (April 1, 2010): The document provided a cost estimate for the repairs and rehabilitation measures indicated in the March 8, 2010 letter. The costs were broken down into two phases, where Phase I repairs were recommended near-term fixes, while Phase II repairs were recommended to be completed concurrent with dam capacity improvements. The estimates were $215,000 for Phase I and $290,000 for Phase II. The letter report did not include a cost estimate to bring the dam into compliance with the spillway flow capacity requirement.

Wright-Pierce Initial Dam Breach Results (May 24, 2010): Wright-Pierce sent a letter report summarizing the dam breach analysis to Mr. Wojnowski, the Newmarket Town Administrator at the time. The report objectives were to verify the dam's hazard classification and provide initial inundation mapping for use in the EAP. The dam breach analysis was conducted for a 100-year flood flow of 8,302 cfs and a "Sunny Day" flow of 272 cfs. The 100-year flow used in the analysis was cited as the same flow indicated in the April 2007 inspection report.

The report indicated that neither the downstream apartments nor any other habitable structure would be impacted by the dam breach. Thus, Wright-Pierce concluded that the dam should be reclassified as a significant hazard dam. The Town sent NHDES a reclassification request letter on June 7, 2010 asking to change the dam's classification from high hazard to significant hazard.

NHDES Review of Initial Dam Breach Results (September 8, 2010): NHDES provided comments to the Town on the initial dam breach results and the hazard reclassification request.

The letter noted that the historic mill building (current proprietor, Durham Book Exchange) abutting the dam's right abutment appeared to be habited, and that a failure of the dam may impact the building's foundation. Thus, regardless of potential impacts to the downstream apartments, it was necessary to maintain the dam's high hazard classification.

Other key points from the letter included:

1) The 100-year inflow used in the initial report (cited in the 2007 inspection report) dated back to a February 1999 inspection report. The 100-year flood flow was determined by using the United States Geological Survey (USGS) streamflow gage (Gage No. 01073500) located on the Lamprey River at Packers Falls and adjusting the 100-year flood, based on drainage area, to the Macallen Dam. NHDES recommended developing a new 100-year inflow for the Macallen Dam impoundment.
2) NHDES suggested conducting an IDF analysis, which may result in a lower design flood than 2.5 times the 100-year flood. Because the high hazard classification is solely due to the historic mill building next to the right abutment, the IDF may be as low as a 100-year flood event.

NHDES 2010 LOD (September 27, 2010): NHDES issued a new LOD. The LOD included a timeline for addressing the deficiencies, which included submitting an OMR form to NHDES, developing an EAP and inundation maps, and various other structural and maintenance-related items. The

LOD also indicated that the Town must submit a permit application with plans and specifications to increase the dam's discharge capacity so that it can "safely pass the design flow (2.5 Q100 or IDF) with one foot of freeboard and no operations" by September 1, 2012. On January 2, 2011, the Town responded to the LOD and signed a form agreeing to address the deficiencies.

Wright-Pierce Final Dam Breach Results (February 6, 2013): Wright-Pierce revisited the initial dam breach analysis based on comments received by NHDES. There was a series of communications between Wright-Pierce and NHDES concerning the hydrology and hydraulics components of the dam breach analysis. The hydrology discussions focused on the rainfall-runoff analysis[10] for the Lamprey River watershed. The hydraulics discussions focused on the Lamprey River/Oyster River "flow split". Ultimately, the Town and NHDES agreed on a 100-year flood flow (which is also the IDF) at the Macallen Dam of 10,259 cfs.

The letter report resulting from this analysis was sent to the Town on February 6, 2013. In addition to describing the final inundation maps and modeling results, the report included a cost estimate for bringing the Macallen Dam into compliance. The costs were broken down into dam repairs costs from the April 2010 letter and dam modification costs necessary to meet the spillway flow capacity requirements.

The report included several potential dam modification scenarios. The modification scenarios included permanently lowering the dam spillway, widening the spillway, raising the dam abutments, or combinations of all three options. Due to site constraints, Wright-Pierce considered any scenario that required widening the spillway crest length beyond 140 feet (currently 70 feet wide) to be infeasible. The report listed five modification scenarios as potentially feasible. The dam modification cost estimates were based on unit (i.e., per unit width or per unit height) costs from other dam removal study estimates; site specific cost estimates were not developed. The costs include $234,000 for the Phase I structural repairs recommended in April 2010, but do not include any potential costs associated with modifying the fish ladder. An itemized cost estimate was not provided in the study report. Table 1 summarizes the spillway improvement alternatives that Wright-Pierce deemed potentially feasible.

[10] NHDES required that a rainfall-runoff analysis be conducted to estimate the 100-year flood flow, rather than relying on the Lamprey River USGS gage.

Table 1: Potentially feasible dam spillway alternatives from February 2013 Wright-Pierce report.

Alternative	Description	Crest Elevation (feet)	Crest Length (feet)	Estimated Cost
Existing	Existing conditions – NOT FEASIBLE, included for comparison purposes	22.18	70	-
2	Lower spillway crest	12.59	70	$1,100,000
3	Increase crest length, lower crest elevation	17.30	140	$2,900,000
5	Raise right (west) abutment 1.8 feet, lower crest elevation	14.39	70	$1,300,000
6	Raise right abutment 1.8 feet, lower crest elevation, increase crest length	19.10	140	$3,000,000
7	Raise right abutment 1.8 feet, lower crest elevation, increase crest elevation, add 3 foot tall crest gate	22.18	140	$4,600,000

Only two of the potential spillway alternatives do not require widening the dam spillway. These scenarios, Alternatives 2 and 5, permanently lower the dam crest by 7.8 feet to 9.6 feet, respectively. Lowering the impoundment will reduce water depths throughout the impounded portion of the Lamprey River. Shallow backwater areas may be permanently dewatered if the dam crest is lowered. For reference, water levels dropped approximately 6.6[11] feet during the fall 2013 drawdown.

Impoundment Hydrology

Flow Data

Figure 13 is a map of the Lamprey River watershed. As noted above, a USGS gage (No. 01073500) is located upstream of the impoundment near Packers Falls that continuously measures flow data. The drainage area at the Packers Falls gage is approximately 183 mi^2. The Lamprey River at the Macallen Dam has a drainage area of approximately 212 mi^2, an increase of approximately 16%. Most of the incremental drainage area between the USGS gage and the Macallen Dam is due to the Piscassic River (drainage area = 23 mi^2), a major tributary to the Lamprey. The Piscassic River has no USGS gage. To estimate Macallen Dam flows, flows from the Packers Falls USGS gage were prorated by a ratio of drainage area (212/183) to represent

[11] This is greater than the maximum drawdown listed above because the pre-drawdown water level was several inches above the spillway crest.

flow at Macallen Dam. An annual flow duration curve[12] for the Macallen Dam is shown in Figure 14, and a monthly flow duration percentiles are shown in Table 2.

Lamprey-Oyster Flow Split

During high flows, water levels in the Macallen Dam impoundment rise considerably. When water levels rise several feet above normal conditions, some of the water backwaters into the Moat Island area (Figure 1) and diverts flow over Route 108 and Longmarsh Road in Durham. This water leaves the Lamprey River watershed and passes into Longmarsh Brook, then Hamel Brook, and finally the Oyster River and over the Oyster River Dam[13]. This diversion reduces the amount of water passing over the Macallen Dam during extreme flood events. Various studies have estimated the portion of this flow that is diverted. The most recent studies looking at the Lamprey-Oyster flow split are the Wright-Pierce February 2013 study and the UNH Lamprey River study[14]. Most recently, the Wright-Pierce February 2013 study estimated the magnitude of flow diversion during a 100-year flood event was approximately 4,261 cfs of the 14,520 cfs flowing into the Macallen Dam impoundment, leaving 10,259 cfs to flow toward the Macallen Dam.

The proportion of water diverted from the Lamprey River into the Oyster River watershed during a flood is a function of the water surface elevation at the Moat Island flow split. Altering the hydraulic controls in either flow path (main stem Lamprey River or the flow diversion path) will change the amount of water that remains in the Lamprey River. Raising the hydraulic controls (and consequently water surface elevations) in the main stem Lamprey River will increase the diversion proportion, while lowering the water surface elevation (such as removing or lowering the Macallen Dam) will decrease the diversion proportion. Similarly, raising the hydraulic controls (and consequently water surface elevations) in the flow diversion reach will reduce the amount of flow diverted to the Oyster River and increase the proportion passing over the Macallen Dam.

This phenomena will be important for the Town to consider in any final hydraulic designs, as lowering the Macallen Dam may decrease the proportion of flow diverted into the Oyster River during flood events. This essentially creates a "moving target," such that as the dam is lowered, it will have to pass more flow in order to meet the freeboard requirement. The Wright-Pierce

[12] Flow duration curves plot the percentage of time a given flow is equaled or exceeded based on a certain period of record.

[13] The Oyster River Dam currently has an LOD for spillway deficiency. The dam's estimated 100-year flood flow is 1,688 cfs. The drainage area at the dam is approximately 20 mi^2.

[14] The document describing this work is a Thesis titled "Consequences of Changing Climate and Land Use to 100-Year Flooding in the Lamprey River Watershed of New Hampshire" by Ann M. Scholz in December 2011.

hydraulic calculations and cost-estimates do not appear to take this factor into account in their spillway alternatives.

Table 2: Lamprey River annual and monthly flow duration curves. Flows are drainage-area prorated from USGS gage No. 01073500 daily average flows. Period of record 10/1/1935-9/30/2011.

Percentile	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	9,324	3,252	5,262	7,339	8,654	9,324	5,052	3,642	2,517	3,372	7,416	2,203	2,719
5	1,119	921	1,024	2,001	1,989	1,018	682	357	262	279	521	927	1,128
10	788	659	732	1,451	1,557	784	484	231	180	166	350	693	838
15	624	541	571	1,172	1,324	678	386	184	137	122	266	563	675
20	512	463	488	1,015	1,123	595	314	151	115	95	213	488	593
25	426	402	431	903	996	523	269	127	97	80	182	420	522
30	360	359	377	825	886	464	230	111	83	68	149	371	465
35	309	323	337	739	790	417	200	96	73	58	129	324	407
40	268	295	306	667	729	380	176	83	62	50	113	286	360
45	230	269	279	601	670	352	159	73	52	43	100	254	325
50	199	244	253	545	622	325	139	64	43	37	87	221	293
55	169	227	232	489	569	299	125	57	36	31	78	196	265
60	141	210	216	434	520	278	112	49	31	25	68	169	237
65	116	191	200	383	477	253	99	43	27	22	56	144	212
70	93	174	181	338	438	230	86	36	23	19	46	123	190
75	74	152	165	303	390	208	76	31	20	16	36	100	164
80	57	133	151	272	355	188	69	28	18	14	28	86	140
85	42	114	126	238	316	160	60	24	15	12	22	71	116
90	27	86	102	203	270	131	50	20	12	10	16	57	79
95	16	55	71	159	217	101	39	15	9	7	11	42	58
100	2	28	36	45	103	52	12	2	2	2	3	10	12
Median	199	244	253	545	622	325	139	64	43	37	87	221	293
Average	340	334	363	732	817	431	239	113	87	83	164	320	399

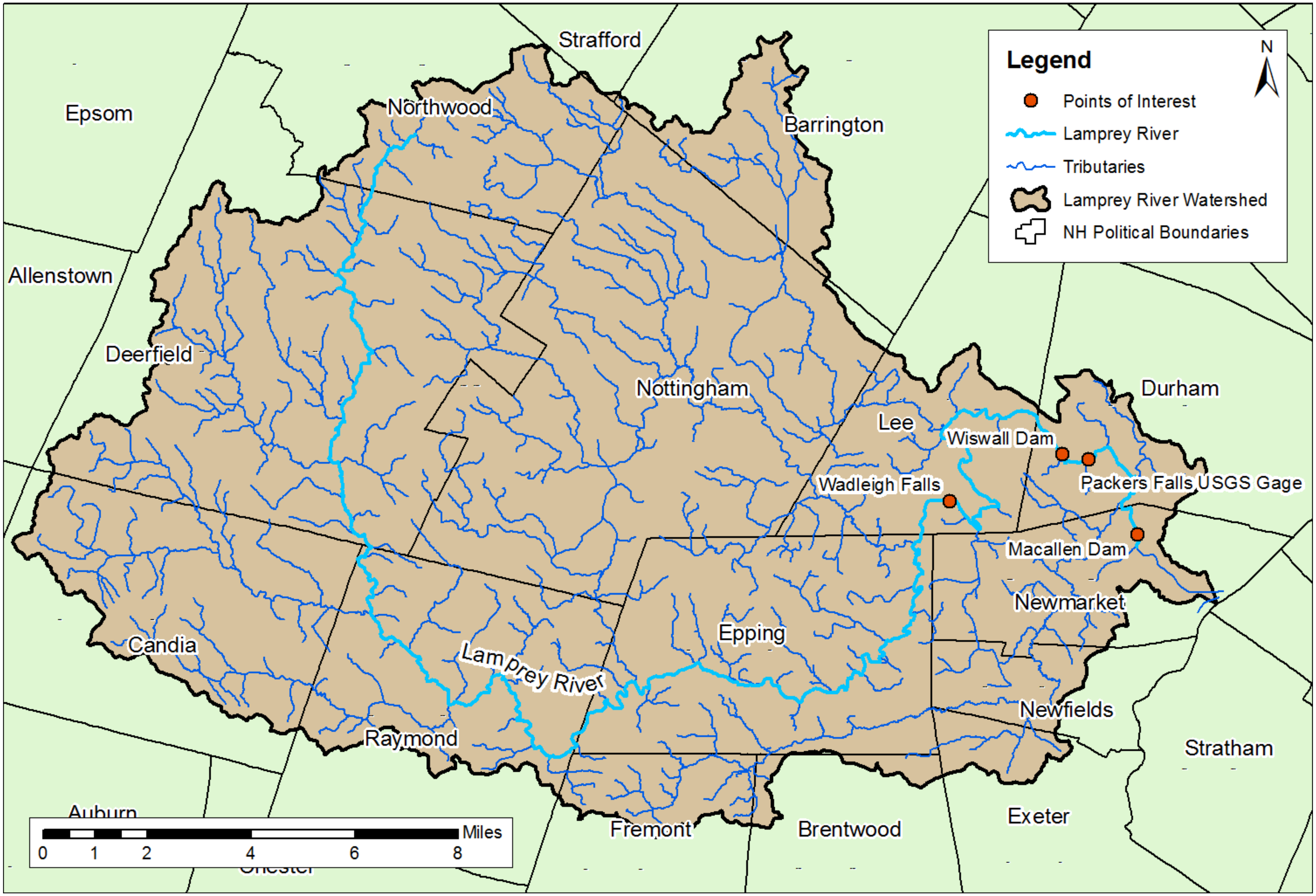

Figure 13: Lamprey river watershed; and points of interest.

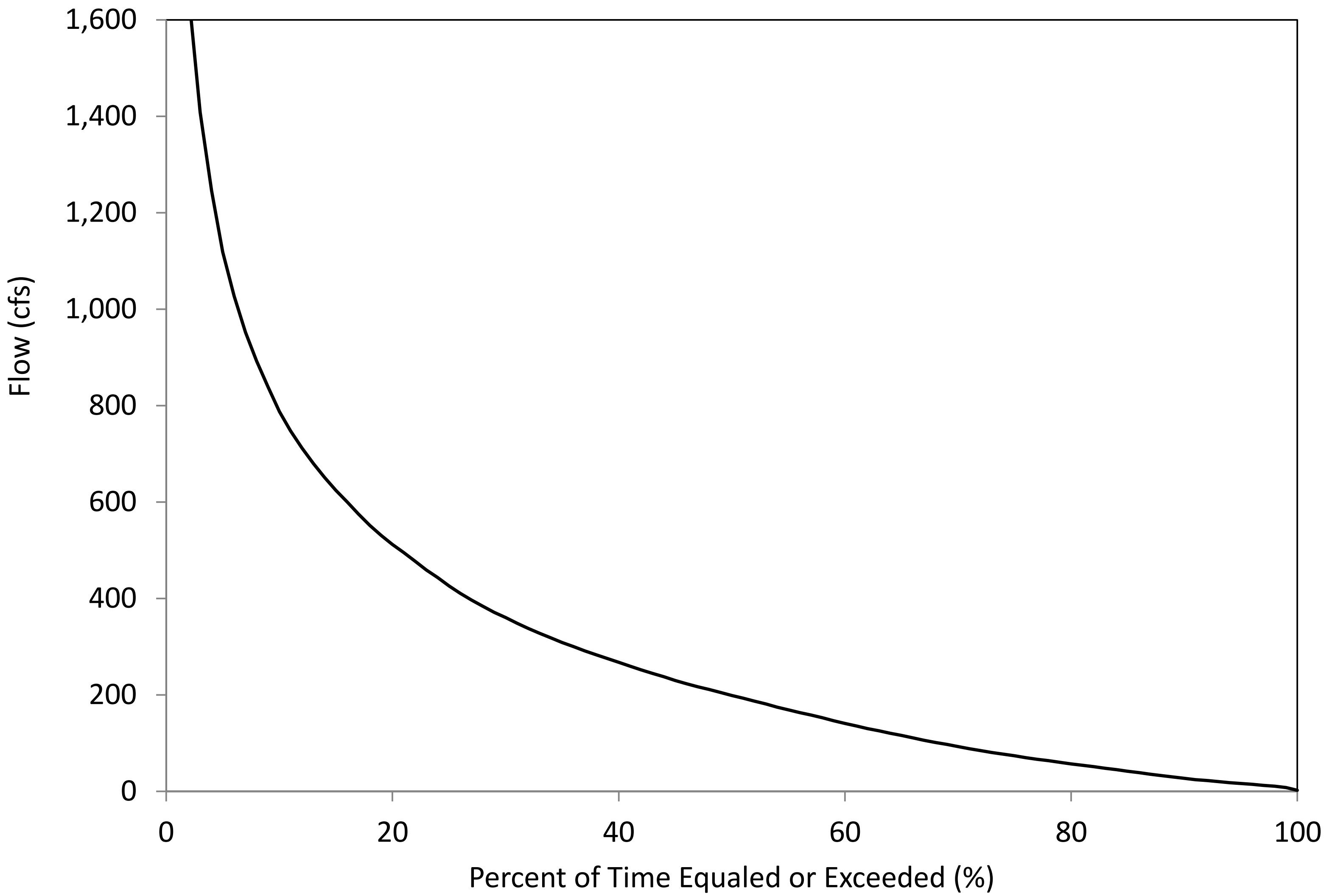

Figure 14: Lamprey River at Macallen Dam flow duration curve. Flows are drainage-area prorated from USGS gage No. 01073500 daily average flows. Period of record 10/1/1935-9/30/2011.

Existing Information

Contaminated Sediment Potential

We researched websites (NHDES One-Stop, EPA Superfund, Remediation Sites, Hazardous Waste Generators, NPDES outfalls, etc.) to determine what, if any spills, or sources of contamination may be present in the project area. The 2012 draft 303(d) list shows that Polyaromatic Hydrocarbons (PAHs) and other chemical impairments are present immediately below the dam. Table 3 lists the impairments for each segment mapped in Figure 15. A summary of the NHDES One-Stop results in the immediate vicinity of the impoundment are in Table 4 below.

Table 3: Water quality impairments in the NH DES 2012 draft 303(d) list.

NH DES Assessment Unit ID	Assessment Unit Name	Use Description	Impairment Name
NH EST 600030709-01-01	Lamprey River North	Aquatic Life	2-Methylnaphthalene, Acenaphthylene, Aluminum, Anthracene, Arsenic, Benzo(a)pyrene (PAHs), Benzo(a)pyrene (PAHs), Benzo[a]anthracene, Benzo[a]anthracene, Cadmium, Chlorophyll-a, Chrysene (C1-C4), Chrysene (C1-C4), Copper, DDD, DDE, DDT, Dibenz[a,h]anthracene, Dibenz[a,h]anthracene, Dissolved oxygen saturation, Fluoranthene, Fluoranthene, Fluorene, Lead, Mercury, Naphthalene, Nickel, Nitrogen (Total), Dissolved Oxygen, Phenanthrene, Pyrene, pH, trans-Nonachlor
NH EST 600030709-01-01	Lamprey River North	Fish Consumption	Polychlorinated biphenyls
NH EST 600030709-01-01	Lamprey River North	Primary Contact Recreation	Chlorophyll-a, Nitrogen (Total)
NH EST 600030709-01-01	Lamprey River North	Shellfishing	Dioxin (including 2,3,7,8-TCDD), Polychlorinated biphenyls
NH EST 600030709-01-02	Lamprey River South	Aquatic Life	Chlorophyll-a, Estuarine Bioassessments, Light Attenuation Coefficient, Nitrogen (Total)
NH EST 600030709-01-02	Lamprey River South	Fish Consumption	Polychlorinated biphenyls
NH EST 600030709-01-02	Lamprey River South	Primary Contact Recreation	Chlorophyll-a, Nitrogen (Total)
NH EST 600030709-01-02	Lamprey River South	Shellfishing	Dioxin (including 2,3,7,8-TCDD), Polychlorinated biphenyls
NH IMP 60030708-03	Piscassic River	Aquatic Life	Dissolved oxygen, Dissolved oxygen saturation, pH
NH IMP 60030709-03	Lamprey River - Macallen Dam Impoundment	Aquatic Life	pH
NH RIV 60030708-07	Piscassic River, PWS, CLS-A	Aquatic Life	Dissolved Oxygen, pH
NH RIV 60030709-09	Lamprey River	Aquatic Life	pH

Table 4: Summary of NHDES One-Stop listed sites near the Macallen Dam impoundment.

Master ID	Status	Description
40773	Inactive	Carlisle Construction, hazardous waste generation, ceased in 2004
66991	Closed	Wojnowski Residence, petroleum remediation in 2012 (#2 fuel oil release)

Master ID	Status	Description
57418	Closed	Cyr residence, 2 teaspoons of #2 fuel oil release from storage tank
61521	Closed	Duplex, Fuel oil released during flooding event
40780	Inactive	Durham Newmarket Animal Hospital, hazardous waste generation (x-ray solution)
43909	Inactive	KB&M Excavating, hazardous waste generation
43901	Inactive	Lamprey River Screen Print, hazardous waste generation (photo silver solution)
43902	Inactive	Great Bay Dental Care, Hazardous Waste Generation (silver)
4362	Closed	Lamprey River Bowling Lanes, leaking underground storage tank, hazardous waste generator, remediation
61653	Closed	Huntington property
60069	Closed	Labone residence, petroleum discharge 2005
51029	Closed	Nichols Ave residence, spill/release
17253	Closed	NHFG site remediation, closed 1991
17258	Closed	PSNH substation, closed 2005
17261	Closed	Marquis residence, petroleum discharge 2001
4363	Active	Jays Newmarket Convenience, site remediation, vapor recovery

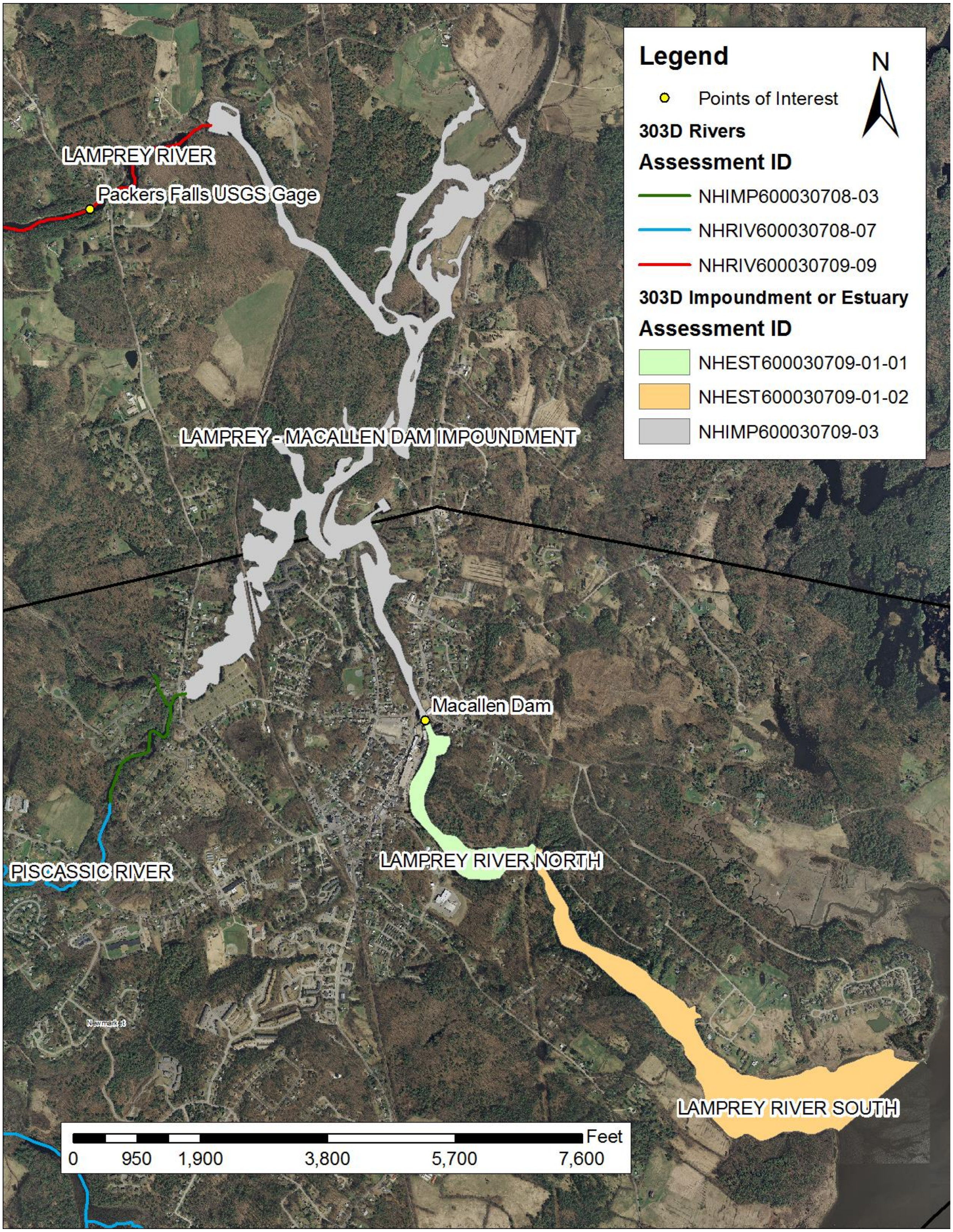

Figure 15: NH 2012 303(d) assessment segments.

Migratory Fish Passage Estimates

The Macallen Dam Denil fish ladder is owned and operated by the NHFGD, and began operation in 1972. The NHFGD annually monitors diadromous and resident fish passing through the fish ladder. The most prominent fish species enumerated are river herring[15] migrating upstream through the ladder to reach spawning habitat from April through June. Passage of other species has also been tracked approximately since 1980. The Macallen Dam fish ladder passage numbers were provided by the NHFGD (NHFGD, unpublished data[16]). The number of fish passed each year varies greatly, but recent years have seen all-time high passage numbers for river herring. Figure 16 shows the number of river herring passed at the Macallen Dam fish ladder, by year, since 1972. The NHFGD estimates indicate approximately 1,400,000 river herring have passed through the Macallen Dam fish ladder since it was first opened in 1972. The NHFGD has documented several species other than river herring also passing through the ladder. These species include Atlantic salmon, sea lamprey, American shad, American eel and various trout, sunfish and perch species, among others.

Efficiency studies have not been completed for the Macallen Dam fish ladder. However, some generalities about passage efficiency at the dam can be made (Personal Communication, C. Patterson, NHFGD, 1/15/2014). These generalities include:

1) The Macallen Dam Denil fish ladder is a 3-foot wide design. This is appropriate for many species such as river herring, but is not for some other migratory fish. For example, American shad prefer a wider (4’ or greater) structure even though some may use a 3’ Denil fish ladder. Other species, however, such as sturgeon, cannot pass through this type of ladder or most fish ladder designs.
2) Young-of-the-year American eels cannot effectively navigate an operating fish ladder because the water velocities inside the ladder are too high for their swimming ability. Therefore, the existing ladder is likely ineffective for passing this life stage of American eel.
3) Denil fishway entrances are designed to constrict access at the structure entrance to provide attraction flows. Therefore, when large schools of fish arrive at once there can be delayed access to the structure. This delay can therefore create an opportunity for increased predation on the population.

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[15] River herring consist of two species: blueback herring and alewife. NHFGD records indicate that the river herring passing through the Macallen Dam fish ladder are almost exclusively alewife. The percentage of blueback herring migrating through the fish ladder has varied between 0% and 12%. However, there is a large blueback herring spawning population below the Macallen Dam that may move upstream under more favorable passage conditions.
[16] Current reports can be found on the NHFGD website: http://www.wildlife.state.nh.us/marine/marine_div_projects.html

4) Fish ladders are generally seasonally operated to accommodate diadromous fish spawning runs (typically coinciding with higher seasonal flows) and are closed to maintain impoundment levels for the rest of the year. Therefore, the potential for fish to utilize the structure for passage is not year-round. Freshwater fish species that may end up below the dam during high flows may not have the ability to regain access into freshwater when the passage system is closed.
5) Even though a fish ladder is installed to allow freshwater access, native migratory fish populations may still perish due to habitat changes that have occurred within an impoundment or because of successive dams creating many impoundments on a river system. This type of habitat destruction and limited upstream access has eliminated Atlantic salmon from most east coast rivers.
6) The fish ladder at the Macallen Dam provides for upstream migration passage but is not designed for downstream passage.

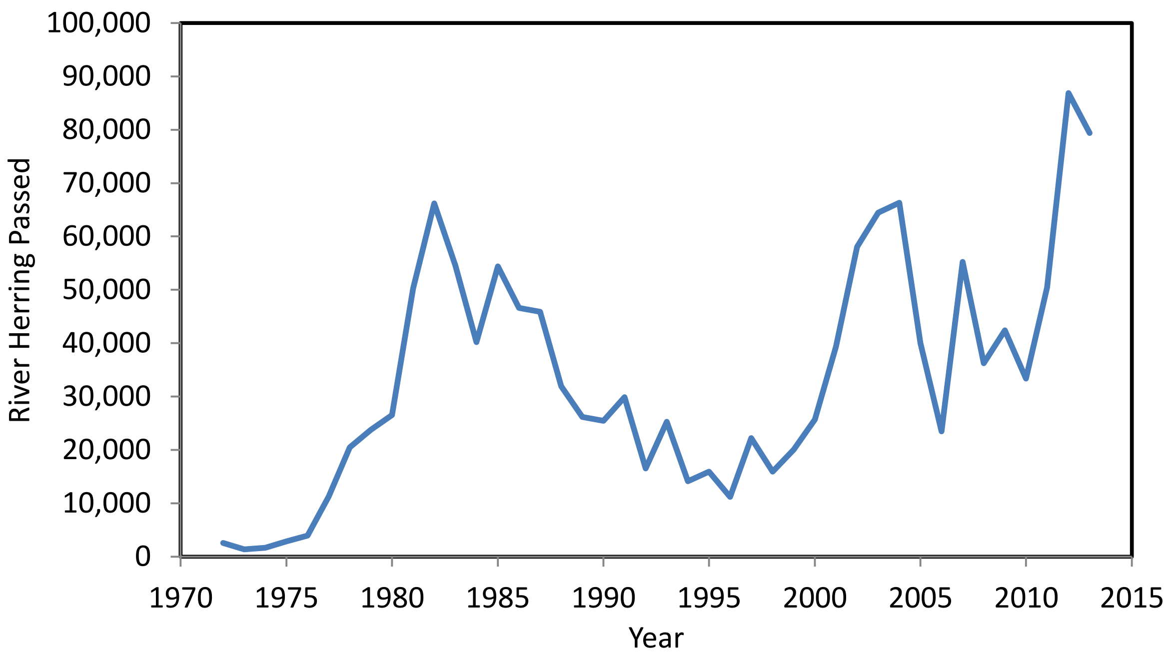

Figure 16: Yearly river herring passed at the Macallen Dam fish ladder. Passage numbers source: NHFG Unpublished Data, provided by C Patterson (NHFGD) on October 30, 2013.

Water Quality Summary

The NH DES 303(d) list indicates several water quality impairments in the Lamprey and Piscassic Rivers in the immediate vicinity of the dam (Table 3). The Lamprey River in the impounded reach is listed as impaired for pH, as is the reach upstream of the impoundment. The Piscassic River upstream of the dam impoundment is listed as deficient for pH and dissolved oxygen and dissolved oxygen saturation. Downstream of the dam, the Lamprey River is deficient for a host of constituents, including pH and dissolved oxygen. The waters downstream of the dam are also listed as deficient for primary contact due to chlorophyll-a and total nitrogen. The fish consumption and shellfishing designated uses are impaired for PCBs.

Veterans Bridge Information

Veteran's Bridge crosses the Lamprey River approximately 250 feet upstream of the Macallen Dam. The NHDOT provided the most recent bridge inspection report from 2011 with photographs (personal communication, D. Powelson, 6/29/2012). They also provided drawings of the bridge superstructure. NHDOT indicated that they did not have any information on the bridge's substructure (i.e., the stone block abutments/foundation). They indicated that no formal scour calculations had been completed on the bridge, but that screening-level assessments indicated that the bridge was at low risk for scour. NHDOT's 2011 underwater inspection indicated that the river bed around the bridge consists of bedrock with cobbles.

The inspection report indicated that the bridge's clear span is approximately 61 feet. GSE's field survey data confirmed this measurement. While the roadway is skewed relative to the river, the openings are parallel to the river flow direction. Field data from the fall of 2013 drawdown indicate that depths are relatively shallow underneath the bridge relative to reaches upstream and downstream of the bridge. This means that the river bed under the bridge may act as a hydraulic control if the dam were to be lowered or removed. This will be more fully studied as part of the hydraulic modeling that has not been completed.

Rare, Threatened and Endangered Species

A brief review of the New Hampshire National Heritage Bureau records indicated that there are several rare, threatened or endangered species located in Newmarket and Durham. Some of these species may live along or be impacted by changes to the river reach impounded by Macallen Dam. A list of the species, by town, is included in Appendix B.

Hydroelectric Generation

Hydroelectric development is regulated by the Federal Energy Regulatory Commission (FERC). FERC is in charge of issuing operating licenses for hydroelectric developments across the nation. GSE has considerable experience with hydroelectric FERC licensing, having been involved in this practice for 20+ years. We offer the following background information to the Town to help explain the hydroelectric licensing process.

Figure 17: Aerial view of Macallen Dam's former hydroelectric works.

There has been considerable discussion about resurrecting hydroelectric power at the Macallen Dam, which previously generated hydroelectric power until the 1950s. It is our understanding that at one time, there was a 500 kilowatt (KW) turbine on the left side of the river and a 50 KW turbine on the right side. It appears that the intake for the 500 KW turbine was located at the arch at the building located adjacent to the dam, and then conveyed flow via an underground penstock to a turbine located in the basement of a building (Figure 17).

The subject of resurrecting hydropower at the Macallen Dam has been pursued on and off for the past few decades based on filings with the FERC. If an Applicant[17] seeks to develop hydropower at Macallen Dam they must file a preliminary permit application with FERC. If the preliminary permit application is approved by FERC, the Applicant is allowed three years to study the site and file a License Application. The Applicant does not need to file a preliminary permit to study a site's hydropower potential, and screening-level work can be done under the risk of another entity filing a preliminary permit on the site. The Applicant, however, must file a preliminary permit with FERC to formally license the site. FERC has established regulations on

[17] Note that the Applicant can be any party- the Town, non-profit, individual, etc. Potential applicants can file a preliminary permit application on the Macallen Dam at any time. If a municipality (Town of Newmarket) files a competing preliminary permit application at the same time as another party, FERC will grant the preliminary permit application to the municipality due to what is termed "municipal preference".

specifically what must be contained within a preliminary permit application, which includes the following Exhibits:

- Exhibit 1: Project Description- includes a description of the proposed project and its operation
- Exhibit 2: Study Plans- includes a list of studies proposed by the Applicant
  Exhibit 3: Statement of Costs and Financing- includes the Applicants estimated study costs and source(s) of financing the project
- Exhibit 4: Project Maps- includes project maps, and proposed layout of the proposed facility

Once the preliminary permit is filed with FERC, they review it for completeness (i.e. does the application address the regulatory requirements). FERC will then "notice" the preliminary permit application and seek comment from federal and state agencies, non-government organizations and any interested parties (collectively referred to as stakeholders) on the proposed development. Typically, the comments will include concerns and issues with the potential development. Commonly stakeholders will request various studies to determine the impact of the proposed project on environmental (wetlands, wildlife, plants, fisheries, etc.), geology and soils, water quality, recreation, aesthetic, and cultural resources.

If an Applicant were to pursue a preliminary permit and went through the regulatory process culminating with the filing of a License Application with FERC, there are several milestones required. We have only noted the key milestones below - the full process includes considerably more than is noted below. These steps are described fully in the FERC regulations.

- A Pre-Application Document (PAD) must be filed with FERC describing the proposed project and all of its known environmental, recreation, water quality, recreation, and cultural resources based on research and input from stakeholders.
- Stakeholders will review the PAD and submit letters requesting studies needed to determine the impact of the proposed project on various resources.
- The Applicant must develop study plans addressing the issues and concerns raised by stakeholders.
- Numerous meetings are held with the stakeholders discussing the study plans and revising them, as needed.
- Once agreed upon, the studies are conducted and reports completed.
- Numerous meetings are held to review the various study findings.
- The Applicant files a Draft License Application, obtain comments, and then files a Final License Application.

- Assuming no issues, FERC will issue a License and the NH Department of Environmental Services will issue a 401 Water Quality Certificate. Thereafter, the Applicant can start developing the site.

To our knowledge, preliminary permits were previously filed on the Macallen Dam as follows:

Preliminary Permit Docket No. P-6602

- DJ Pitman International Corporation filed a preliminary permit application in August 1982.
- Stakeholders filed comments on the permit application.
- FERC issued a Draft Environmental Assessment in March 1988.
- FERC notified the Applicant that the project could not be economically and financially feasible in June 1988.
- DJ Pitman International Corporation withdrew their preliminary permit application in July 1988.

Preliminary Permit Docket No. P-11823

- The Town of Newmarket filed a preliminary permit application in September 1999.
- Stakeholders filed comments on the preliminary permit application.
- The Town of Newmarket withdrew their preliminary permit application in March 2000.

Note that FERC maintains a website where more recent communications – like the information for preliminary permit Docket No. P-11823 -- is readily available on-line at the following website: http://elibrary.ferc.gov/idmws/search/fercgensearch.asp. Once on the website, enter the docket number- in this case "P-11823". We suggest the Town review the letters filed with FERC that are on the website to gain a better understanding of the issues and concerns.

Relative to the preliminary permit filed in 1999, the Applicant proposed installing a turbine at the base of the existing gate structure and raising the impoundment elevation by installing 2-foot flashboards[18]. The permit application called for one 600 KW turbine that could operate with flows between 80 and 400 cfs. The reported estimated annual generation was 2,300,000 kilowatt-hours (KWH).

The Applicant estimated the costs for conducting the studies related to engineering, environmental, economic and financing studies as $50,000.

[18] Raising the elevation of the impoundment by 2 feet increases the head available for generation. The greater the head, the higher the generation.

Following the filing of the preliminary permit application with FERC, comments were filed by federal and state agencies, non-government organizations and citizens. Many issues and concerns were noted and presumably the Town came to the conclusion that it was not worth pursuing the project given that they withdrew the preliminary permit in March 2000.

It is not the intent of our study to evaluate the feasibility of hydropower development at Macallen Dam. However, if the Town opts to develop hydropower at Macallen Dam the following should be considered:

- There are upfront costs associated with the FERC licensing process, including studies, as listed above. Based on our experience, the $50,000 estimate in the 1999 preliminary permit application is grossly underestimated.
- There are capital costs associated with developing the site (powerhouse, turbine, substation, transmission, etc).
- There are still costs associated with modifications to the dam necessary to pass the 100-year flood per the NHDES. Developing hydroelectric generation will not ease these requirements.
- The average annual electricity consumption for a US residential customer in 2011 was 11,280 KWh/year (US Energy Information Administration). Assuming that approximately 2,300,000 kWH/year could be produced annually (per the 1999 permit application), it would power approximately 204 homes.
- Assuming the wholesale price of power was $50 to $60/MWH (US Energy Information Administration), a facility producing approximately 2,300,000 kWH/year would yield between $115,000 and $138,000 annually if it was selling to the wholesale power market.
- Other issues could be investigated that could increase the value of the facility's energy. These could include renewable energy credits, certified low-impact hydropower, etc.

Appendix A: Weir Coefficient Memo

Introduction

Gomez and Sullivan is conducting hydraulic modeling (HEC-RAS) of the Lamprey River in the Macallen Dam impoundment as part of a study for the Town of Newmarket (Town) to evaluate the feasibility of potentially removing the dam. As part of our work, we will be calculating the depth of water above the existing Macallen Dam spillway under a variety of flows. This will require quantifying the Macallen Dam spillway's weir coefficient. The weir coefficient is part of the weir equation, which is used to calculate a spillway's flow capacity. The weir equation is described by the equation:

$Q = CLH^{1.5}$, where

Q = is quantity of flow passing over the weir (cfs),
C= is the weir coefficient (feet$^{0.5}$),
L= is the length of the weir (feet), in this case the length of the spillway is 70 ft, and
H= is the depth of water above the weir crest (feet).

The purpose of this memo is to describe our process for quantifying the Macallen Dam's weir coefficient.

As part of our background research, we obtained the Lamprey River HEC-RAS model that Wright-Pierce (W-P) developed as part of their work for the Town. W-P used their model to conduct work associated with their dam break and classification analysis. The objective of their work was to determine the Macallen Dam's 100-yr flood flow (while following NHDES guidelines) and the Macallen Dam's hazard classification. The final report, dated February 6, 2013, describes the work conducted by W-P, including the dam's 100-yr flood flow (10,259 cfs) and the dam's hazard classification (high). The report also includes a cost estimate for several potentially feasible alternatives to bring the dam into compliance with NHDES Dam Bureau dam safety requirements for a high hazard dam[19]. In reviewing the W-P HEC-RAS model and Appendix G of the February W-P report, we noted that a weir coefficient of 2.60 and 2.63 was used in the model and report calculations, respectively.

[19] NHDES Dam Bureau dam safety rules require a dam to pass the design flow with 1-ft of freeboard and no manual operations. The design flow for the Macallen Dam, which is classified as High Hazard, was determined by the W-P study to be the 100-yr flood flow (10,259 cfs).

Methodology

Gomez and Sullivan typically determines weir coefficients by referencing the Handbook of Hydraulics, by Brater and King. The sixth edition is cited in this document for convenience, since the seventh edition has converted all of the equations, tables and coefficients to SI units from English units.

While 2.63 is commonly cited as the weir coefficient for a broad-crested weir, Brater and King notes that the weir coefficient can change with the water height, H:

"*Experiments on broad-crested weirs have been performed by Blackwell, Bazin, Woodburn, the U.S. Deep Waterways Board, and the U.S. Geological Survey. These experiments cover a wide range of conditions as to head, breadth, and height of weir. Considerable discrepancy exists in the results of the different experimenters, especially for heads below 0.5 ft. For heads from 0.5 to about 1.5 ft the coefficient becomes more uniform, and for heads from 1.5 to that at which the nappe becomes detached from the crest, the coefficient as given by the different experiments is nearly constant and equals approximately 2.63. When the head reaches one to two times the breadth, the nappe becomes detached and the weir becomes essentially sharp-crested. The effect on discharge of roughness of the crest can be computed by applying the principals of flow in open channels.*"

The dam's geometry is different than a typical broad-crested weir. In particular, the dam features a sloping upstream face (2:1 slope, 3.5' rise, 7' long), with a 1' tall by 2.5' wide "step" on the top of the dam (Figure A-1). There is also a small metal lip in the center of the spillway that is approximately 2" tall. Given the dam's shape, it is possible that the dam spillway could act more like a trapezoidal weir under certain flow conditions. To remain conservative (i.e., not overestimate the spillway flow capacity), however, we suggest modeling the dam as a broad-crested weir rather than as a trapezoidal weir.

Results

Brater and King

Table 5-3 in Brater and King (Figure A-2) tabulates weir coefficients for various weir head and breadth combinations for broad crested weirs. If the flow is high enough to produce 4 feet of head, with a breadth of 2.5 feet, then Table 5-3 would indicate a weir coefficient of 3.32. If we look in Brater and King Table 5-11 (Figure 3), which is for trapezoidal weirs with a sloped upstream face and a downstream vertical face (similar to Macallen Dam), the weir coefficient for a 2:1 (horizontal:vertical) sloped upstream face such as Macallen Dam may be as high as 3.64-3.73, depending on the crest width. Again, while the dam may act more like a trapezoidal weir under some conditions, we believe it is prudent to model the dam spillway as a broad crested weir. Thus, under conditions where the head is 4.0 feet or higher, we believe it is appropriate to model the Macallen Dam spillway with a weir coefficient of 3.32. For model scenarios that produce less than 4.0 ft of head, or alternatives where the dam breadth is increased, it will be necessary to re-evaluate the spillway's weir coefficient using Brater and King's Table 5-3.

Empirical Data

The New Hampshire Fish and Game Department (NHFG) provided GSE with measured water depths from a consistent location near the Dam's west retaining wall during the eel passage season from 2001 through 2007. The daily average flows at the Packers Falls USGS gage during the measurements ranged from 11 cfs to 1,910 cfs. The measured depths were not measured relative to the spillway crest, so the crest elevation was estimated by extrapolating the measurements at low flows (measurements were taken at flows as low as 11 cfs) to the approximate elevation at 0 cfs. The readings were then normalized to the estimated crest elevation. Water depth measurements indicated the water surface was no more than 3 ft above the spillway crest under all measured conditions, so it was assumed that there was no flow diversion into the Oyster River basin.

The data were plotted versus drainage-area prorated daily average flows from the Packers Falls USGS Gage (Figure A-4). Two elevation versus flow rating curves were developed using the weir equation, with one curve assuming C=2.63 and one curve assuming C=3.32. The flow vs. elevation curve assuming C=3.32 appeared to fit the data better than the curve assuming C=2.63.

Conclusion

This document described our proposed method for calculating the Macallen Dam spillway's weir coefficient. We propose to model the dam as a broad-crested weir and to use the weir coefficients listed in Table 5-3 of Brater and King's sixth edition. For heads greater than 4.0 ft, this translates to a weir coefficient of 3.32. We used historic water level measurements collected by NHFGD to validate this estimation. The validation data showed that a weir coefficient of 3.32 was appropriate for heads between 0.5 ft to 2.0 ft. One can expect the weir coefficient at higher heads to remain at or above those measured at lower heads. Thus, a weir coefficient of 3.32 appears to be appropriate for most situations we will model in this study.

A weir coefficient of 3.32 is approximately 26% higher than the 2.63 weir coefficient used in the W-P report. This translates into the spillway being able to pass 26% more flow than W-P estimated, for a given headwater elevation. Therefore, our hydraulic model and calculations will show lower water surface elevations than the W-P report indicated, when comparing similar flows. This may also reduce the portion of flow that diverts to the Oyster River at the Route 108 flow split under high flow events.

Figure A-1: Side-view of Macallen Dam.

Table 5-3. Values of C in the Formula $Q = CLH^{3/2}$ for Broad-crested Weirs

Measured head in feet, H	Breadth of crest of weir in feet									10.5 *	
	0.50	0.75	1.00	1.50	2.00	2.50	3.00	4.00	5.00	10.00	15.00
0.2	2.80	2.75	2.69	2.62	2.54	2.48	2.44	2.38	2.34	2.49	2.68
0.4	2.92	2.80	2.72	2.64	2.61	2.60	2.58	2.54	2.50	2.56	2.70
0.6	3.08	2.89	2.75	2.64	2.61	2.60	2.68	2.69	2.70	2.70	2.70
0.8	3.30	3.04	2.85	2.68	2.60	2.60	2.67	2.68	2.68	2.69	2.64
1.0	3.32	3.14	2.98	2.75	2.66	2.64	2.65	2.67	2.68	2.68	2.63
1.2	3.32	3.20	3.08	2.86	2.70	2.65	2.64	2.67	2.66	2.69	2.64
1.4	3.32	3.26	3.20	2.92	2.77	2.68	2.64	2.65	2.65	2.67	2.64
1.6	3.32	3.29	3.28	3.07	2.89	2.75	2.68	2.66	2.65	2.64	2.63
1.8	3.32	3.32	3.31	3.07	2.88	2.74	2.68	2.66	2.65	2.64	2.63
2.0	3.32	3.31	3.30	3.03	2.85	2.76	2.72	2.68	2.65	2.64	2.63
2.5	3.32	3.32	3.31	3.28	3.07	2.89	2.81	2.72	2.67	2.64	2.63
3.0	3.32	3.32	3.32	3.32	3.20	3.05	2.92	2.73	2.66	2.64	2.63
3.5	3.32	3.32	3.32	3.32	3.32	3.19	2.97	2.76	2.68	2.64	2.63
4.0	3.32	3.32	3.32	3.32	3.32	3.32	3.07	2.79	2.70	2.64	2.63
4.5	3.32	3.32	3.32	3.32	3.32	3.32	3.32	2.88	2.74	2.64	2.63
5.0	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.07	2.79	2.64	2.63
5.5	3.32	3.32	3.32	3.32	3.32	3.32	3.32	3.32	2.88	2.64	2.63

Figure A-2: Weir-coefficients from Brater and King (sixth edition) for broad crested weirs, as a function of dam breadth and water height above the weir crest.

Table 5-11. Values of C in the Formula $Q = CLH^{3/2}$ for Weirs of Trapezoidal Cross Section with the Upstream Face Inclined and the Downstream Face Vertical

Slope of upstream face	Width of crest in feet	Head in feet, H								
		1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
Hor. Vert.										
2 to 1	0.33	3.85	3.82	3.79	3.77	3.75	3.73	3.70	3.67	3.64
2 to 1	0.66	3.41	3.57	3.65	3.70	3.72	3.72	3.73	3.73	3.73
3 to 1	0.66	....	....	3.57	3.57	3.57	3.57	3.57	3.57	3.57
4 to 1	0.66	....	....	3.48	3.48	3.48	3.48	3.48	3.48	3.48
5 to 1	0.66	....	....	3.39	3.39	3.39	3.39	3.39	3.39	3.39

Figure A-3: Weir coefficients from Brater and King (sixth edition) for trapezoidal weirs with a sloped upstream face and a vertical downstream face.

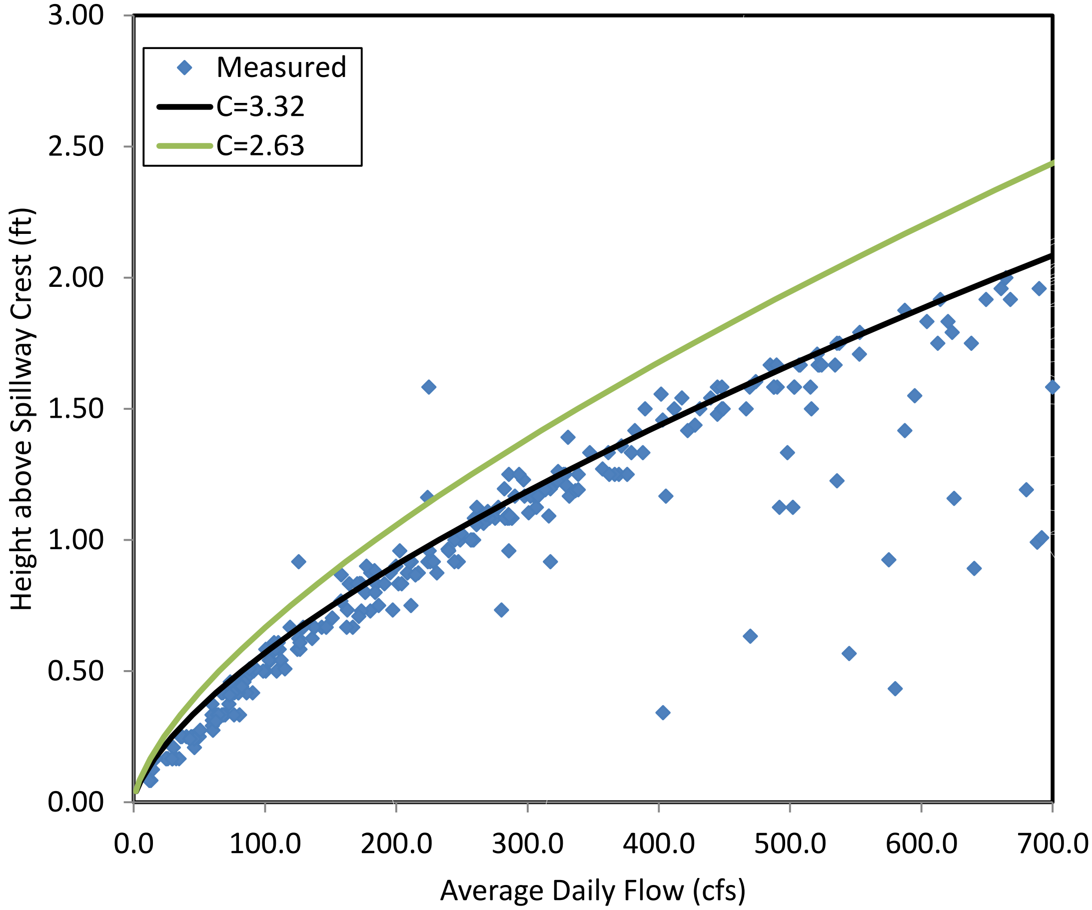

Figure A-4: Flow vs. water depth measurements and calculations for two different weir coefficients (2.63 and 3.32). Additional measurements at daily average flows greater than 700 cfs are not shown. Measurements at higher flows (> 250 cfs) with lower heights above the spillway crest than the curve show may be due to the dam gates being opened during the measurements.

Appendix B: New Hampshire Natural Heritage Bureau Documentation

Town Flag	Species or Community Name	Listed? Federal	State	# reported last 20 yrs Town	State
Newmarket					
	Natural Communities - Terrestrial				
**	Rich Appalachian oak rocky woods	--	--	1	16
	Natural Communities - Palustrine				
**	Low-gradient silty-sandy riverbank system	--	--	1	4
**	Red maple - black ash swamp	--	--	2	17
**	Swamp white oak floodplain forest	--	--	1	7
	Natural Communities - Estuarine				
**	High salt marsh	--	--	3	14
	Low brackish riverbank marsh	--	--	Historical	7
**	Low salt marsh	--	--	1	6
**	Salt marsh system	--	--	1	6
**	Sparsely vegetated intertidal system	--	--	1	1
**	Subtidal system	--	--	1	3
	Plants				
*	Atlantic mudwort (*Limosella australis*)	--	E	1	2
	blunt-lobed cliff fern (*Woodsia obtusa*)	--	E	Historical	9
***	climbing hempvine (*Mikania scandens*)	--	E	2	11
	Downy False Foxglove (*Aureolaria virginica*)	--	E	Historical	15
	eastern grasswort (*Lilaeopsis chinensis*)	--	E	Historical	4
**	great bur-reed (*Sparganium eurycarpum*)	--	T	3	20
	green rockcress (*Boechera missouriensis*)	--	T	Historical	14
	hairy wood brome (*Bromus pubescens*)	--	E	Historical	6
**	horned-pondweed (*Zannichellia palustris*)	--	E	1	5
**	little-headed spikesedge (*Eleocharis parvula*)	--	T	2	23
**	Marsh Elder (*Iva frutescens*)	--	T	2	11
	one-glumed spikesedge (*Eleocharis uniglumis*)	--	T	Historical	12
**	perennial saltmarsh American-aster (*Symphyotrichum tenuifolium*)	--	E	1	6
	Philadelphia panicgrass (*Panicum philadelphicum*)	--	E	Historical	8
	prairie wedgescale (*Sphenopholis obtusata*)	--	E	Historical	2
	prolific yellow-flowered knotweed (*Polygonum ramosissimum* ssp. *prolificum*)	--	E	Historical	10
**	red-root umbrella sedge (*Cyperus erythrorhizos*)	--	E	1	3
**	saltmarsh agalinis (*Agalinis maritima*)	--	E	1	10
	seaside brookweed (*Samolus valerandi* ssp. *parviflorus*)	--	E	Historical	5
	slender blue iris (*Iris prismatica*)	--	E	Historical	11
	Trailing Bush-clover (*Lespedeza procumbens*)	--	E	Historical	3
**	tufted yellow-loosestrife (*Lysimachia thyrsiflora*)	--	T	1	10
	Tundra Alkali Grass (*Puccinellia pumila*)	--	E	Historical	7
	Vertebrates - Mammals				
***	Northern Long-eared Bat (*Myotis septentrionalis*)	--	SC	1	9
	Vertebrates - Birds				
**	Bald Eagle (*Haliaeetus leucocephalus*)	--	T	1	88
**	Osprey (*Pandion haliaetus*)	--	SC	2	103

Listed? E = Endangered T = Threatened SC = Special concern

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*** = Extremely high importance
** = Very high importance
* = High importance

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Town Flag	Species or Community Name	Listed? Federal	State	# reported last 20 yrs Town	State
**	Saltmarsh Sparrow (*Ammodramus caudacutus*)	--	SC	1	8
	Sedge Wren (*Cistothorus platensis*)	--	E	Historical	4
	Sora (*Porzana carolina*)	--	SC	Historical	2
	Vertebrates - Reptiles				
***	Blanding's Turtle (*Emydoidea blandingii*)	--	E	34	709
***	Spotted Turtle (*Clemmys guttata*)	--	T	2	119
**	Wood Turtle (*Glyptemys insculpta*)	--	SC	3	193
	Vertebrates - Amphibians				
**	Jefferson/Blue-spotted Salamander Complex (*Ambystoma hybrid* pop. *3*)	--	--	1	8
	Vertebrates - Fish				
**	American Eel (*Anguilla rostrata*)	--	SC	2	177
	Invertebrates - Ants & Wasps				
**	Fen Ant (*Lasius minutus*)	--	--	1	2
**	Seaside Dragonlet (*Erythrodiplax berenice*)	--	--	1	12
Newport					
	Plants				
	hollow Joe-Pye weed (*Eutrochium fistulosum*)	--	E	Historical	10
	Vertebrates - Birds				
	Common Nighthawk (*Chordeiles minor*)	--	E	Historical	9
	Vertebrates - Reptiles				
**	Wood Turtle (*Glyptemys insculpta*)	--	SC	2	193
	Invertebrates - Mollusks				
****	Brook Floater (*Alasmidonta varicosa*)	--	E	1	32
Newton					
	Natural Communities - Palustrine				
***	Atlantic white cedar - yellow birch - pepperbush swamp	--	--	2	20
**	Seasonally flooded Atlantic white cedar swamp	--	--	1	3
***	Swamp white oak floodplain forest	--	--	1	7
	Temperate minor river floodplain system	--	--	Historical	7
	Plants				
**	weak stellate sedge (*Carex seorsa*)	--	E	1	3
	Vertebrates - Reptiles				
*	Blanding's Turtle (*Emydoidea blandingii*)	--	E	1	709
**	Spotted Turtle (*Clemmys guttata*)	--	T	3	119
	Invertebrates - Dragonflies & Damselflies				
**	Mocha Emerald (*Somatochlora linearis*)	--	--	1	4
	Invertebrates - Mollusks				
**	Eastern Pond Mussel (*Ligumia nasuta*)	--	SC	1	8

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Town Flag	Species or Community Name	Listed? Federal	State	# reported last 20 yrs Town	State
Durham					
	Natural Communities - Terrestrial				
**	Hemlock - beech - oak - pine forest	--	--	1	11
**	Rich Appalachian oak rocky woods	--	--	1	16
	Natural Communities - Palustrine				
**	Herbaceous seepage marsh	--	--	1	5
**	Kettle hole bog system	--	--	1	24
**	Red maple - lake sedge swamp	--	--	1	1
**	Red maple - red oak - cinnamon fern forest	--	--	1	2
**	Red maple - Sphagnum basin swamp	--	--	1	8
*	Red maple floodplain forest	--	--	1	15
	Natural Communities - Estuarine				
**	Brackish marsh	--	--	2	12
**	High salt marsh	--	--	3	14
**	Salt marsh system	--	--	1	6
**	Sparsely vegetated intertidal system	--	--	1	1
**	Subtidal system	--	--	1	3
	Plants				
	American Waterwort (*Elatine americana*)	--	E	Historical	2
**	Beck's water-marigold (*Bidens beckii*)	--	T	2	12
**	Black Maple (*Acer nigrum*)	--	T	2	10
**	blunt-lobed cliff fern (*Woodsia obtusa*)	--	E	1	9
**	crested sedge (*Carex cristatella*)	--	E	3	12
	Downy False Foxglove (*Aureolaria virginica*)	--	E	Historical	15
	Dwarf Glasswort (*Salicornia bigelovii*)	--	E	Historical	7
	Engelmann's Quillwort (*Isoetes engelmannii*)	--	E	Historical	15
	forked rush (*Juncus dichotomus*)	--	E	Historical	1
	Giant Rhododendron (*Rhododendron maximum*)	--	T	Historical	13
**	great bur-reed (*Sparganium eurycarpum*)	--	T	6	20
	greater fringed-gentian (*Gentianopsis crinita*)	--	T	Historical	28
**	green rockcress (*Boechera missouriensis*)	--	T	1	14
	hairy wood brome (*Bromus pubescens*)	--	E	Historical	6
	horned-pondweed (*Zannichellia palustris*)	--	E	Historical	5
**	ivy-leaved duckweed (*Lemna trisulca*)	--	E	1	5
	lake quillwort (*Isoetes lacustris*)	--	E	Historical	5
	Leafy Bulrush (*Scirpus polyphyllus*)	--	E	Historical	3
	little-headed spikesedge (*Eleocharis parvula*)	--	T	Historical	23
**	Loesel's wide-lipped orchid (*Liparis loeselii*)	--	T	1	25
**	long-leaved pondweed (*Potamogeton nodosus*)	--	T	1	24
*	Marsh Elder (*Iva frutescens*)	--	T	2	11
	Marsh Horsetail (*Equisetum palustre*)	--	E	Historical	12
	Netted Chain Fern (*Woodwardia areolata*)	--	E	Historical	4
	Northern Blazing Star (*Liatris novae-angliae*)	--	E	Historical	16
**	northern tubercled bog-orchid (*Platanthera flava* var. *herbiola*)	--	E	1	11
	Pale Duckweed (*Lemna valdiviana*)	--	E	Historical	4

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Town Flag	Species or Community Name	Listed? Federal	State	# reported last 20 yrs Town	State
	Philadelphia panicgrass (*Panicum philadelphicum*)	--	E	Historical	8
	prairie wedgescale (*Sphenopholis obtusata*)	--	E	Historical	2
**	prolific yellow-flowered knotweed (*Polygonum ramosissimum* ssp. *prolificum*)	--	E	1	10
	Purple Milkweed (*Asclepias purpurascens*)	--	E	Historical	4
	purple virgin's-bower (*Clematis occidentalis*)	--	E	Historical	25
	Rigid Sedge (*Carex tetanica*)	--	--	Historical	1
	rufous bulrush (*Scirpus pendulus*)	--	E	Historical	5
**	saltmarsh agalinis (*Agalinis maritima*)	--	E	1	10
	sharp-flowered manna grass (*Glyceria acutiflora*)	--	E	Historical	9
	smooth black sedge (*Carex nigra*)	--	E	Historical	11
	smooth rockcress (*Boechera laevigata*)	--	E	Historical	6
*	stout dotted smartweed (*Persicaria robustior*)	--	E	1	6
**	tufted yellow-loosestrife (*Lysimachia thyrsiflora*)	--	T	1	10
	Tundra Alkali Grass (*Puccinellia pumila*)	--	E	Historical	7
*	Turk's-cap lily (*Lilium superbum*)	--	E	1	1
	Virginia three-seeded-Mercury (*Acalypha virginica*)	--	E	Historical	5
**	water-plantain crowfoot (*Ranunculus ambigens*)	--	E	1	3
	Vertebrates - Mammals				
**	New England Cottontail (*Sylvilagus transitionalis*)	--	E	1	21
	Vertebrates - Birds				
**	Bald Eagle (*Haliaeetus leucocephalus*)	--	T	1	88
**	Common Tern (*Sterna hirundo*)	--	T	1	9
	Golden-winged Warbler (*Vermivora chrysoptera*)	--	SC	Historical	4
**	Least Bittern (*Ixobrychus exilis*)	--	SC	1	4
**	Osprey (*Pandion haliaetus*)	--	SC	5	103
**	Sedge Wren (*Cistothorus platensis*)	--	E	1	4
**	Upland Sandpiper (*Bartramia longicauda*)	--	E	1	6
	Vesper Sparrow (*Pooecetes gramineus*)	--	SC	Historical	12
	Vertebrates - Reptiles				
***	Blanding's Turtle (*Emydoidea blandingii*)	--	E	17	709
	Eastern Hognose Snake (*Heterodon platirhinos*)	--	E	Historical	41
**	Northern Black Racer (*Coluber constrictor constrictor*)	--	T	1	54
***	Spotted Turtle (*Clemmys guttata*)	--	T	4	119
**	Wood Turtle (*Glyptemys insculpta*)	--	SC	2	193
	Vertebrates - Fish				
	American Brook Lamprey (*Lampetra appendix*)	--	E	Historical	2
**	American Eel (*Anguilla rostrata*)	--	SC	7	177
	Atlantic Sturgeon (*Acipenser oxyrinchus*)	--	--	Historical	1
**	Banded Sunfish (*Enneacanthus obesus*)	--	SC	1	30
**	Redfin Pickerel (*Esox americanus americanus*)	--	SC	1	32
**	Sea Lamprey (*Petromyzon marinus*)	--	SC	1	5
**	Swamp Darter (*Etheostoma fusiforme*)	--	SC	1	13
	Invertebrates - Butterflies & Moths				
	A Noctuid Moth (*Chaetaglaea cerata*)	--	--	Historical	5

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Town Flag	Species or Community Name	Listed? Federal	State	# reported last 20 yrs Town	State
	A Noctuid Moth (*Chytonix sensilis*)	--	--	Historical	3
	A Noctuid Moth (*Feltia manifesta*)	--	--	Historical	2
	Bog Elfin (*Callophrys lanoraieensis*)	--	--	Historical	1
	Columbine Duskywing (*Erynnis lucilius*)	--	--	Historical	4
	Frosted Elfin (*Callophrys irus*)	--	E	Historical	7
	Lyre-tipped Spreadwing (*Lestes unguiculatus*)	--	--	Historical	5
***	Ringed Boghaunter (*Williamsonia lintneri*)	--	E	2	13
**	Seaside Dragonlet (*Erythrodiplax berenice*)	--	--	2	12
	Taiga Bluet (*Coenagrion resolutum*)	--	--	Historical	17
East Kingston					
	Natural Communities - Palustrine				
**	Atlantic white cedar - yellow birch - pepperbush swamp	--	--	1	20
	Red maple - sensitive fern swamp	--	--	Historical	10
**	Swamp white oak basin swamp	--	--	1	5
***	Swamp white oak floodplain forest	--	--	1	7
	Temperate minor river floodplain system	--	--	Historical	7
	Plants				
	Acadian Quillwort (*Isoetes acadiensis*)	--	E	Historical	3
**	American featherfoil (*Hottonia inflata*)	--	E	1	7
	Engelmann's Quillwort (*Isoetes engelmannii*)	--	E	Historical	15
	Vertebrates - Amphibians				
**	Jefferson/Blue-spotted Salamander Complex (*Ambystoma hybrid* pop. *3*)	--	--	1	8
	Vertebrates - Fish				
	American Eel (*Anguilla rostrata*)	--	SC	Historical	177
	Invertebrates - Mollusks				
**	Eastern Pond Mussel (*Ligumia nasuta*)	--	SC	1	8
Easton					
	Natural Communities - Terrestrial				
***	High-elevation spruce - fir forest system	--	--	1	10
**	Semi-rich mesic sugar maple forest	--	--	1	20
	Natural Communities - Palustrine				
**	High-gradient rocky riverbank system	--	--	1	9
*	Medium level fen system	--	--	1	62
	Plants				
*	Lindley's American-aster (*Symphyotrichum ciliolatum*)	--	T	1	12
	Mountain Firmoss (*Huperzia appressa*)	--	E	Historical	14

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